Automated Billing System
For Public Utilities

by

Saeed AbdulWahid Al-Qatari

A Thesis Presented to the

FACULTY OF THE COLLEGE OF GRADUATE STUDIES

KING FAHD UNIVERSITY OF PETROLEUM & MINERALS

DHAHRAN, SAUDI ARABIA

In Partial Fulfillment of the
Requirements for the Degree of

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In

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King Fahd University of Petroleum and Minerals (Saudi Arabia), 1994

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COLLAGE OF GRADUATE STUDIES

This thesis, written by ***SAEED ABDULWAHID AL-QATARI*** under direction of his Thesis Advisor and approved by his Thesis Committee, has been presented to and accepted by the Dean of the Collage of Graduate Studies, in partial fulfillment of the requirement for the degree of ***MASTER OF SCIENCE in ELECTRICAL ENGINEERING.***

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كلية الدراسات العليا
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This Thesis is dedicated to my Father, Mother,
Wife and Family

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خلاصة الرسالة

اسم الطالب: سعيد عبد الواحد القطري
عنوان الدراسة: جهاز الفواتير الأتوماتيكي للخدمات العامة
التخصص: هندسة كهربائية
تاريخ الشهادة: أبريل ١٩٩٤

حاليا" أنظمة الفواتير للخدمات العامة (الكهرباء، الماء/الغاز، والتلفون) منفصلة، غير دقيقة، مكلفة، بطيئة، وغير مرنة، وليست مأمونة. ولهذا كانت هناك محاولات كثيرة لتحويل الأنظمة التقليدية الى أنظمة أتوماتيكية. ولكن كانت معظم تلك المحاولات مكلفة وغير قابلة للتطبيق الواسع. ففي هذه السالة، تم اقتراح نظام موحد يحتوي على جهاز قارئ بطاقات الأثمان حيث يعتبر حلا" متكاملا" للخدمات العامة لتحويل الأنظمة التقليدية الى أنظمة أتوماتيكية. بطاقة الأثمان تستخدم من قبل العميل لدفع المبالغ المستحقة في موقع الجهاز (منزل، محل، ...). الذي يعتمد على طرق قياس رقمية باستخدام المعالجات التحكمية الصغيرة (Microcontrollers).

الجهاز المقترح يتكون من بنيتين. البنية الأولى هي الأجزاء الألكترونية التي تتكون من عداد الطاقة الرقمي، عداد الماء/الغاز الرقمي، عداد التلفون، جهاز قارئ بطاقات الأثمان، أجهزة التحكم في الخدمة (يستخدم في توصيل و فصل الخدمة أتوماتيكيا")، و المعالج التحكمي. ان أجهزة التحكم في الخدمة مفيدة في حالة اذا كان العميل لايدفع المبالغ المستحقة عليه. فقد تم أختبارالطرق المقترحة لقياس الطاقة الكهربائية المستهلكة باستخدام البرنامج (MathCad) بمختلف سرعة العينات، دقة العينات، وتأخر العينات في حالتين: ١) في وجود التشويهات ٢) في غير وجود التشويهات. البنية الثانية هي البرامج الخاصة بتشغيل الجهاز التي تضمنت كتابة برنامجين، وهما: ١) برنامج تصليح أعطال الجهاز ٢) برنامج تشغيل واستثمار الجهاز.

لقد تم تصميم، بناء، واختبار نموذج من الجهاز المقترح باستخدام الكمبيوترالشخصي الذي تم تحويلة ليوافق خصائص المعالجات التحكمية الصغيرة. حيث أثبتت التجارب على الجهاز المقترح كفاءتة في اعطاء الدقة المطلوبة.

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ABSTRACT

Saeed Abdulwahid Al-Qatari

AUTOMATED BILLING SYSTEM FOR PUBLIC UTILITIES

Major Field: Electrical Engineering

Currently, the billing systems for public utilities (Electricity, Water/gas, and Telephone) are stand alone, inaccurate, costly, and slow. Several attempts were made to automate the billing systems. However, none of these systems was cost-effective for wide range implementation. In this thesis, an integrated system for the three utilities and a credit card reader are proposed.

The proposed system has two structures. The first structure is hardware which consists of a digital energy meter, a digital water/gas meter, a telephone call meter, a credit card reader, and a microcontroller. The proposed techniques for electrical energy metering are simulated for different sampling rate, sampling precision, and sampling delay under harmonics and no harmonicas cases. Each meter circuit is designed, built and tested. The second structure is software which includes the development of system trouble shooting program and system operation program. The integrated system is tested and has proven to be stable, reliable and easy to maintain within its accuracy.

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

Generating the monthly utility bills (electricity, water/gas, and telephone) in a fast, accurate, reliable, and cost-effective manner, is a major concern for the utility organizations. Also, bill payment in a reliable and flexible method is a major concern for both consumers and utilities.

Figure 1.1 shows the existing billing systems for electricity and water/gas services. These systems are based on mechanical meters that are used to record the consumption. On a periodical basis, the electricity consumption in kilowatt-hour (KWH) and water/gas consumption in multiple of 1,000 gallons are directly read from the meters by the utility personnel. Then, the data are taken to the utility and fed to the central computer for generating the statement charges. After that, the bills are sent to the customers by mail or via

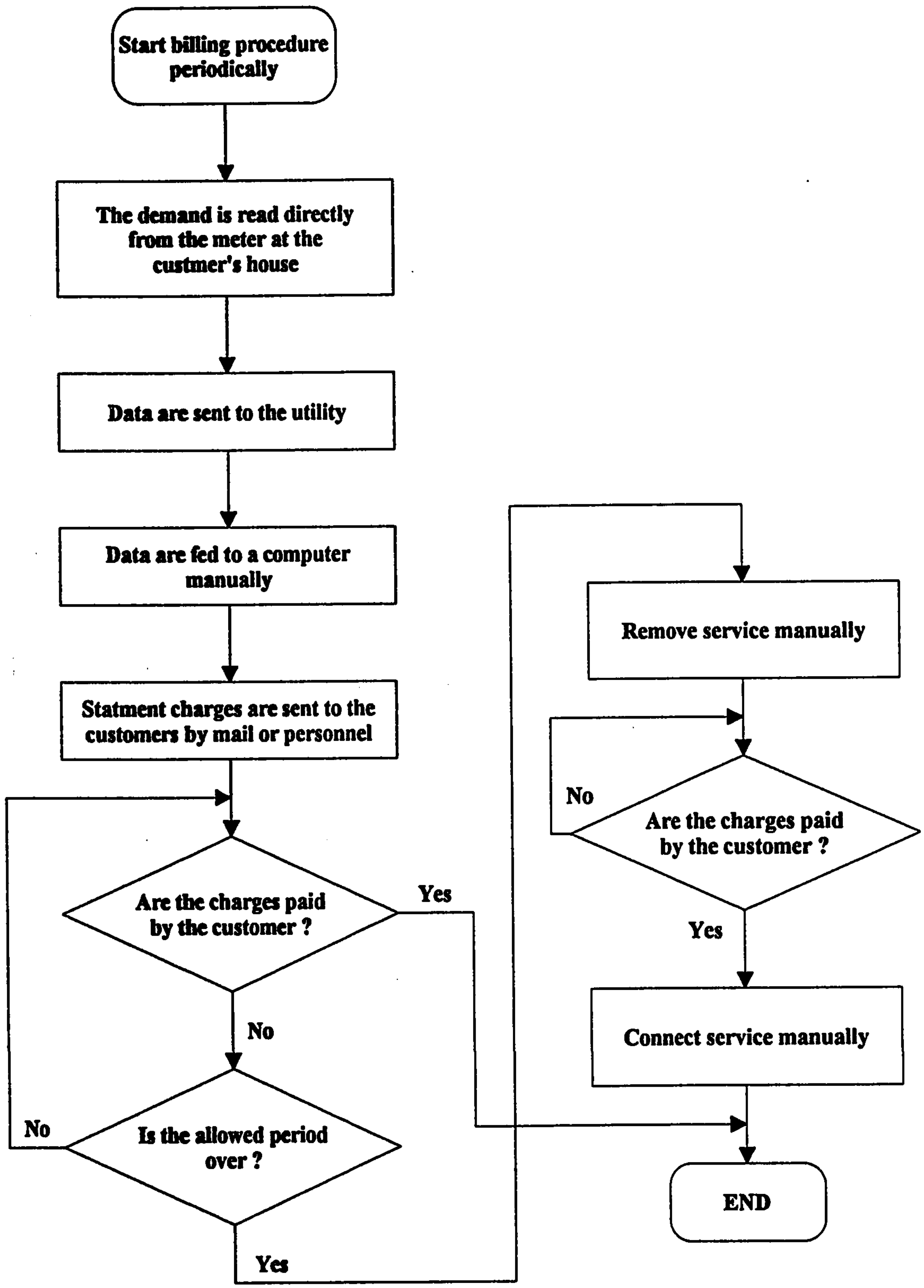

Figure 1.1, Existing Energy and Water/Gas Billing Systems Flow Chart

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the utility personnel. If the consumer does not pay within the allowed period, specified by the utility, the service will be disconnected manually until payment is made.

The existing telephone billing system is shown in Figure 1.2. This system differs from the electricity and water/gas billing systems in two ways. First, telephone call periods are recorded at the central office (CO) and automatically fed to a computer by which the statement charges are generated, on a periodical basis. Second, if the consumer does not pay within the allowed period, specified by the utility, the service will be disconnected remotely, but manually, until payment is made.

In the following sections, the problems associated with the existing billing systems are discussed. Then an overview of the present solutions taken to overcome such problems are presented, and finally a new solution is proposed as an attempt to overcome the problems that are associated with the existing billing systems.

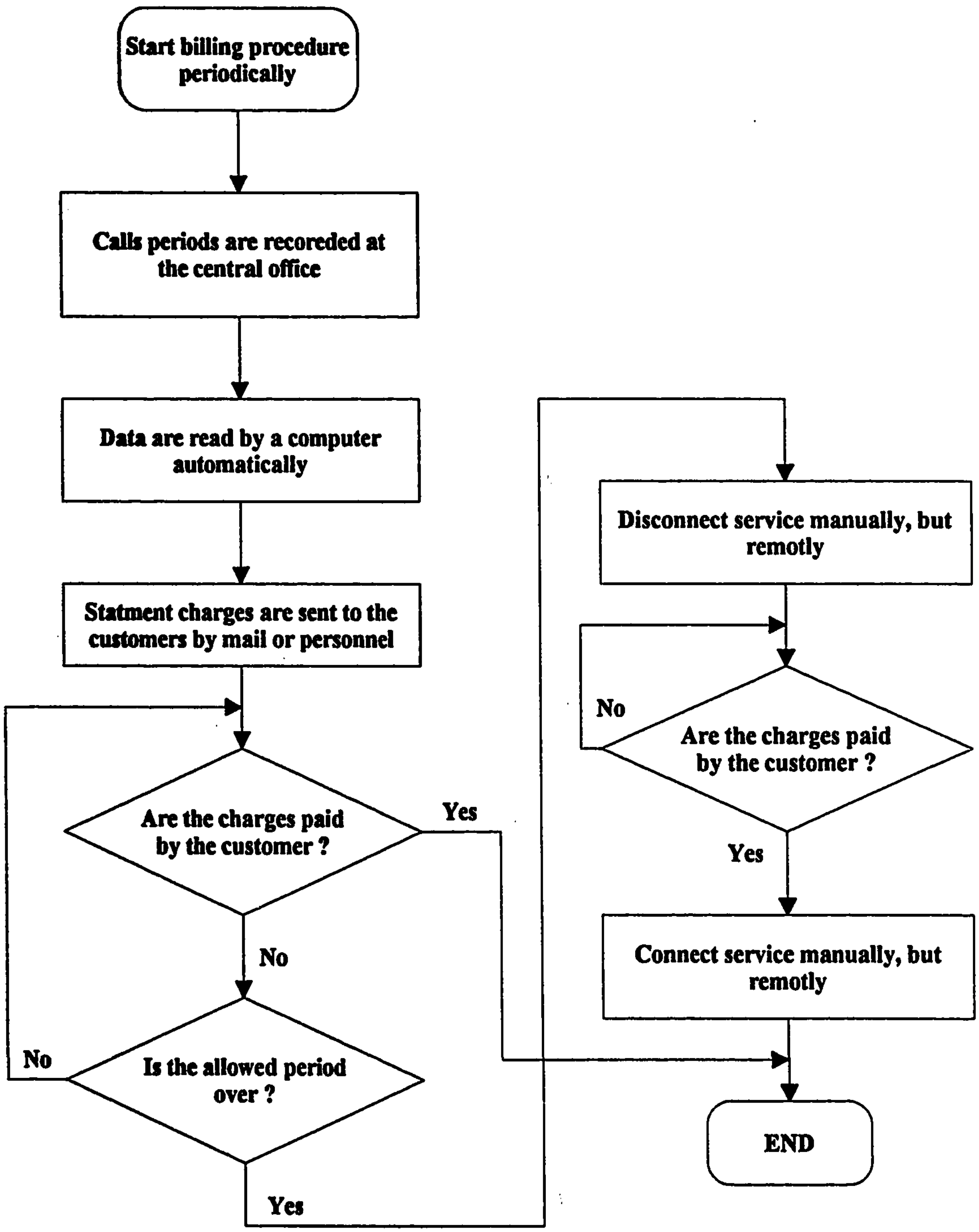

Figure 1.2, Telephone Billing System Flow Chart

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1.2 PROBLEM DESCRIPTION

The existing billing systems for the public utilities (electricity, water/gas, and telephone) have several disadvantages and can be summarized as follows:

- The electricity and water/gas consumption are read directly from the meters. This leads to inaccurate readings and cost estimations by the utilities, specially when the meters are inside the home or in a hard-to-access place [33].

- Getting into customers houses may cause disturbance to them.

- The collected data from the electricity and water/gas meters are manually fed to a computer to generate the statement charges. This may leads to typing errors.

- The statement charges for the utilities (electricity, water/gas, and telephone) are sent to the customers by mail or via utilities personnel, which may leads to addressing errors.

- The customer is not aware of the costs and service consumption until he receives the statement charges. This might create problems for the customer at the time of payment.

- Payment is required by the customer periodically at a fixed period. If the customer does not pay within that period, the service is disconnected manually until payment is made.

- The billing systems require manpower, which significantly increases the network operation costs.

- The existing equipment for the utilities at the customer's house are not secured. Steeling electricity, water/gas, and telephone services can be easily done by any body.

Based on the above discussion, the existing billing systems are very costly, slow, inaccurate, and do not provide the consumer with the flexibility and reliability for payment.

1.3 PRESENT SOLUTION

Several attempts have been made to overcome the above mentioned problems associated with the traditional metering systems. One of the most efficient attempt is through remote metering [5, 11, 14, 16, 19, 27, 28].

As discussed previously, telephone call charges are registered remotely. Therefore, remote metering for the electricity and water/gas services will improve the billing system to achieve the same level of performance as the telephone service billing system.

Communication represents the major roadblock in remote metering, because of the heavy costs involved and the fact that no single technique has overriding advantages [5]. A wide variety of communication techniques have been considered to make remote metering possible. Nine potential technologies fall into four groups [5, 11, 14, 19]:

- Physically connected media including wire lines, coaxial cables, and fiber-optic cables.

- Power-line media including distribution-line carrier communication and power-frequency communication.

- Electromagnetic propagation media including UHF/VHF radio, AM/FM radio, and spread-spectrum satellite radio.

- Common-carrier media, primarily telephone company lines.

Choosing the communication media, will determine the system configuration, technical capabilities, type of equipment, costs, and operating characteristics. Table 1.1 summarizes the required communication equipment for the communication technologies. Tables 1.2, 1.3 & 1.4 summarize the required technical capabilities, costs, and operational attributes of communication technologies.

Even though accurate and fast readings are obtained, bills payment is still performed based on the old billing procedure. In addition, remote metering is very

Technology	Master Station	Media to submaster station	Submaster station	Media to remote terminal	Remote terminal units (RTUs)	Field interfaces
Physical media						
Wire lines	Modems	Metallic wire lines	Signal repeaters	Metallic wire lines	Conventional Scada	Conventional individual units separate from RTU
Coaxial Cable	Head-end broadcast equipment	Coaxial cable	Signal repeaters	Coaxial cable	Scada RTUs with high speed digital face	
Fiber-optic cable	Digital interface	Fiber optic cable	Signal repeaters	Fiber optic cable	Scada RTUs with high speed digital face	
Power-line carriers						
Power harmonics	Modems	Common carriers, private cable, or private microwave	Feeder signal injectors	Feeder distri-bution lines	Specially designed low-data-rate RTUs	may be integrated with RTU
Distribution-line carrier	Modems	Common carriers, private cable, or private microwave	Feeder signal injectors	Feeder lines with line condit-ioning equipment	Specially designed low-data-rate RTUs	
Broadcast media						
AM/VHF radio	Signal injection equipment and modems	Common carriers, private cable, or private microwave	Multiple receivers	Free space propaga-tion	Specially designed low-data-rate RTUs	may be integrated with RTU
UHF/VHF radio	Modems	Common carriers, private cable, or private microwave	Multiple receivers	Free space propaga-tion	Conventional Scada RTUs	Conventional individual units, separate from RTU
Satellite radio	Earth terminal	Free space propag-ation	satellite transp-onder	Free space propaga-tion	Conventional Scada RTUs with earth terminal	
Common-carrier						
Common-carrier lines	Modems	None	None	Leased facilit-ies	Conventional Scada RTUs	Conventional individual units, separate from RTU

Table 1.1, Communication equipment required for remote metering

Technology	Frequency availability	Geographical coverage	Data rates, bits per second	State of development
Physical media				
Wire lines	No use of broadcast spectrum	Limited by wire right of way	300 to 9600	Well proven
Coaxial Cable	No use of broadcast spectrum	Limited by cable system penetration	9600 to 1.544 million	
Fiber-optic cable	No use of broadcast spectrum	limited by fiber-optic system penetration	9600 to 1.544 million	
Power-line carriers				
Power harmonics	Utilizes power-line frequencies below 200 Hz	Full coverage for each feeder implemented	60	Full-scale field test
Distribution-line carrier	Uses unregulated power-line carrier frequencies (3-30 kHz)	Full coverage for each feeder implemented	Up to 76	
Broadcast media				
AM/VHF radio	Uses existing AM radio frequencies and VHF splinter frequencies	Excellent AM coverage but limited by line of sight for VHF return	Up to 100	Full-scale field test
UHF/VHF radio	20 UHF pairs available; VHF if UHF more scarce	Limited by line of sight	1200 to 9600	Well proven
Satellite radio	Up and down links must be coordinated for local area	Virtually any earth location	1200 to 1.544 million	Limited field testing
Common-carrier				
Common-carrier lines	Already licensed to common carrier	Anywhere common-carrier service is available	300 to 9600	Well proven

Table 1.2, Technical capabilities of Communication technologies

Technology	Relative startup cost	Cost dependence for adding RTU	Relative cost of RTU	Target cost for remote two-way transceiver $	Likely cost-effective quantity
Physical media					
Wire lines	Highest cost for installation of wire lines	Direct function of wire length installed	High cost, full-function Scada RTUs	100-300	1-500
Coaxial Cable	Highest cost for installation of cable system	Direct function of cable length installed	High cost, full-function Scada RTUs	500-1000	1-50
Fiber-optic cable	Highest cost for installation of cable system	Direct function of cable length installed	High cost, full-function Scada RTUs	500-1000	1-10
Power-line carriers					
Power harmonics	Moderate cost to install feeder injection equipment	Direct function of number of feeders implemented	Low cost, limited-function RTUs	100-300	100
Distribution-line carrier	Moderate cost for injection, conditioning equipment	Direct function of number of feeders implemented	Low cost, limited-function RTUs	100-300	100
Broadcast media					
AM/VHF radio	Moderate cost for AM injection and VHF receiver	Dependent upon number of VHF submasters required	High cost, limited-function RTUs	100-300	100
UHF/VHF radio	Lowest cost to install UHF submasters	Dependent upon number of UHF submasters required	Low cost, full-function Scada RTUs	3000-5000	10-100
Satellite radio	Highest cost for earth terminal	Dependent upon transponder power and bandwidth	High cost, full-function Scada RTUs	100-300	1-50
Common-carrier					
Common-carrier lines	Lowest cost for installation	Function of mileage from master	High cost, full-function Scada RTUs	100-300	1-50

Table 1.3, Relative costs of Communication technologies

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Technology	Expandability	Reliability	Maintainability	Security from catastrophe
Physical media				
Wire lines Coaxial Cable Fiber-optic cable	Additional wire line required per RTU	Excellent for buried cable; fair of aerial cable	Breaks hard to find repair; 8-24 hour repair time	Susceptible to catastrophe cable cut
Power-line carriers				
Power harmonics	Each feeder requires injection equipment	Dependent upon operation of 60-Hz power	Only one feeder at a time must be repaired; 2-8 hour repair time	Communication lost if power lost; otherwise falls one feeder at a time
Distribution-line carrier	Each feeder requires injection and conditioning equipment	Dependent upon physical continuity of distribution line	Only one feeder at a time must be repaired; 2-8 hour repair time	Falls only one feeder at a time
Broadcast media				
AM/VHF radio	Each new geographical area requires a VHF submaster	Excellent; depends only upon radio electronics	Maintenance by replacing electronic unit; 1-2 hour repair time	Failure if radio lost or single failures of VHF submasters
UHF/VHF radio	Each new geographical area requires a UHF submaster	Excellent; depends only upon radio electronics	Maintenance by replacing electronic unit; 1-2 hour repair time	Fails one geographical area (UHF submaster) at a time
Satellite radio	One transponder can handle at least 1000 RTUs	Excellent; depends upon highly reliable satellite	Maintenance by replacing electronic unit; 1-2 hour repair time	Lost of satellite transponder fails
Common-carrier				
Common-carrier lines	Essentially unlimited expansion, one circuit at a time	Common carrier generally inferior to other media	Maintenance by common carrier; 2-24 hour repair time	Exchange office failures and cable cuts

Table 1.4, Operational attributes of Communication technologies

expensive to cover all houses. Furthermore, The major disadvantages of such technique are the followings:

1. The overall network operation costs are not reduced.
2. Customer awareness of his consumption and costs are not achieved.
3. Payment is required periodically. Therefore, the flexibility is not achieved.
4. Manpower is required for bill processing.
5. Manpower is required for disconnecting and connecting the service due to bad credit.

1.4 PROPOSED SOLUTION

This thesis proposes a new direction to overcome the problems associated with the existing utilities billing systems. A design of an Automated Billing System (ABS) that can be used for electricity, telephone, and water/gas services, simultaneously or individually will be presented. When an integrated system is used for the utilities, system maintenance coordination is required by the different organizations. The ABS is, mainly, introduced to reduce significantly the overall network operation costs and provide the flexibility and reliability for customers to pay any time, but before money rundown. An encoded magnetic-stripe card is used by the customer for payment at his location.

Figure 1.3 shows the new system configuration, which is composed of six major block circuits. The first block is a telephone call meter and control circuit, which is used to provide call progress for calculating call charges and connect/disconnect the telephone source. The second block is an electrical energy meter and control circuit used to measure the energy consumption for three phase feeders and connect/disconnect the electricity supply. This circuit replaces the induction watthour meter with a digital watthour meter using a microcontroller. The third block is a water/gas meter and control circuit, which is used to provide water/gas flow rate for calculating the consumption charges. This circuit replaces the existing mechanical meter with an electronic meter. The fourth block is an alarm circuit which is used to provide overload, overdue, and miscellaneous (system) alarms. The fifth block is a magnetic-stripe Card reader, which is used to read the costumer credits. The sixth block is a microcontroller

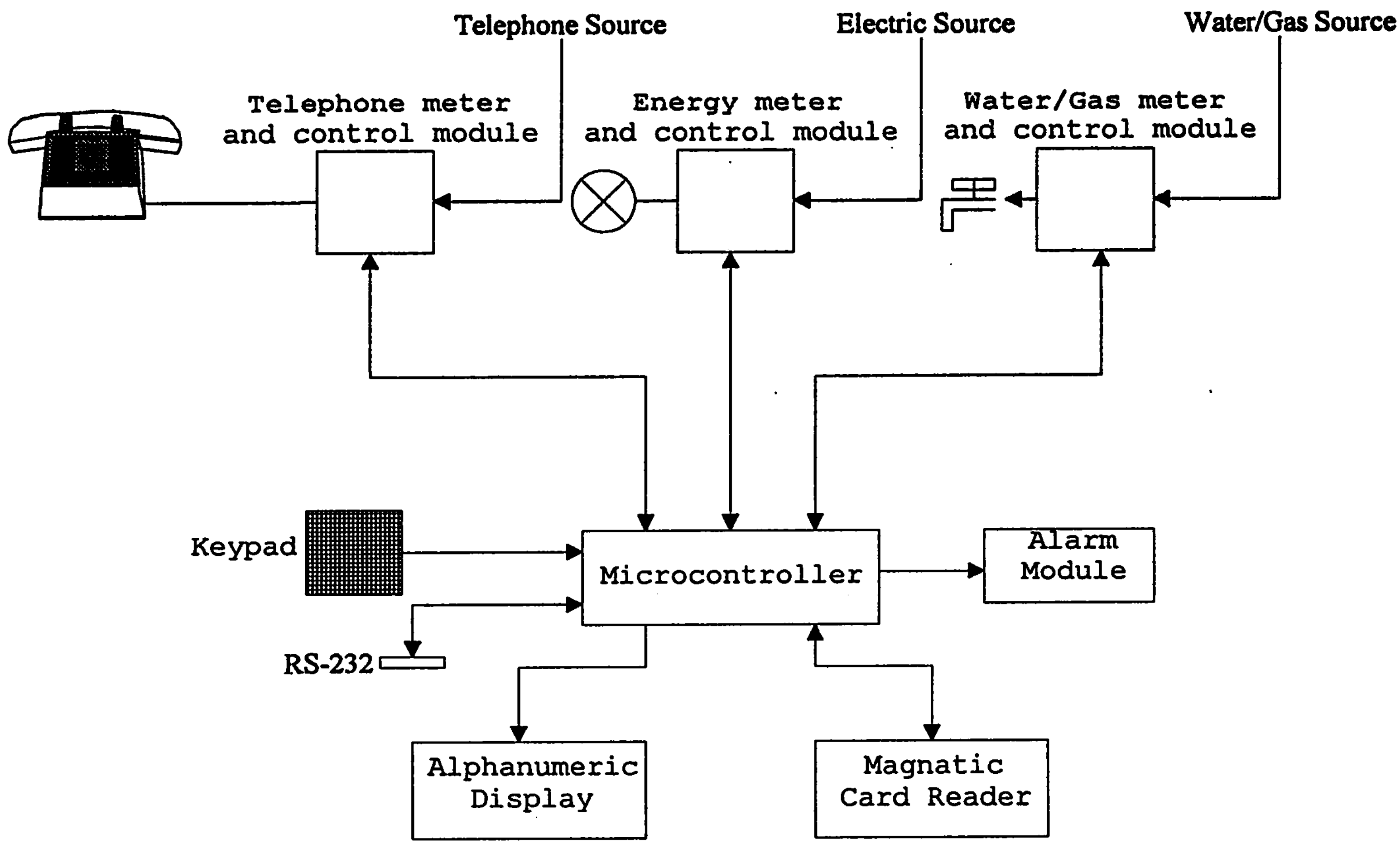

Figure 1.3
Proposed Automated Billing System for Public Utilities Block Diagram

that is used to collect data from the circuits and store them in the data memory. Also, the microcontroller is used to generate alarms, read magnetic cards, and, automatically, disconnect and connect services. Through periodical system maintenance, if the utility found that one or more services is disconnected for a period of time, the service will be removed completely from the customer.

1.5 PROPOSED SYSTEM ACHIEVEMENT

The major issues involved in the achievement of the proposed system are:

1. The type of technique that will be used in the digital wattmeter to be selected.
2. The digital wattmeter circuitry to be designed and implemented.
3. The type of flow sensor to be selected.
4. The water/gas meter circuitry to be designed and implemented.
5. The telephone calls circuitry to be designed and implemented.

6. The magnetic card reader technique to be adopted.
7. The complete system to be integrated and designed.
8. A prototype system will be built and tested.
9. A software package to be developed to monitor and control the overall operation.

1.6 THESIS ORGANIZATION

In Chapter 2, several existing wattmeters that are used for energy metering including the induction wattmeters, the analog wattmeters, and the digital wattmeters will be reviewed. Then, the mechanical and the electronic flow meters are also investigated. Furthermore, the telephone call metering process is discussed. In Chapter 3, the proposed energy, water/gas, and telephone metering and billing methods are explained. Chapter 4 is devoted to the hardware design, software algorithms, and operation of the proposed system. In Chapter 5, the proposed system is evaluated by building a prototype system. Conclusions of the research, along with recommendations for further future work are presented.

CHAPTER 2

LITERATURE SURVEY

In this chapter, the concept of the existing watthour (energy) meters, water/gas flow meters, telephone call metering process, magnetic cards and crediting techniques, and microcontroller are discussed. Furthermore, their types, properties, operation, billing methods, and standards are investigated. Finally, some of the existing metering automation systems are presented.

2.1 EXISTING ENERGY (WATTHOUR) METERS THEORY AND OPERATION

Currently, the electrical energy is measured by either induction or solid-state watthour meters. Solid-state Watthour meters could be based on analog or digital computation. This section explores the different type of watthour meters and states the advantages and disadvantages. Also, their operation and billing methods are presented.

2.1.1 INDUCTION (ELECTROMECHANICAL) WATTHOUR METERS

For many decades, the only type of watthour meter was an induction device that measured the energy consumption. This device measures the consumed energy over a period of time by causing an aluminum disc to rotate (and hence drive a number of counting dials) at a speed proportional to the product of the voltage and the load current. That is, a given number of revolutions of the disc is equivalent to one kilowatt-hour (KWH). Figure 2.1 shows the structure of a single-phase watthour meter in schematic form [21].

The current coil is connected in series with the load, and the voltage coil is connected across the load. Both coils are wound on a metal frame of special design, providing two magnetic circuits. The disc is suspended in the air-gap of current-coil field, which causes eddy currents to flow in the disc. The reaction of the eddy currents and the field of voltage coil creates a torque on the disc, causing it to rotate. The developed torque is proportional to

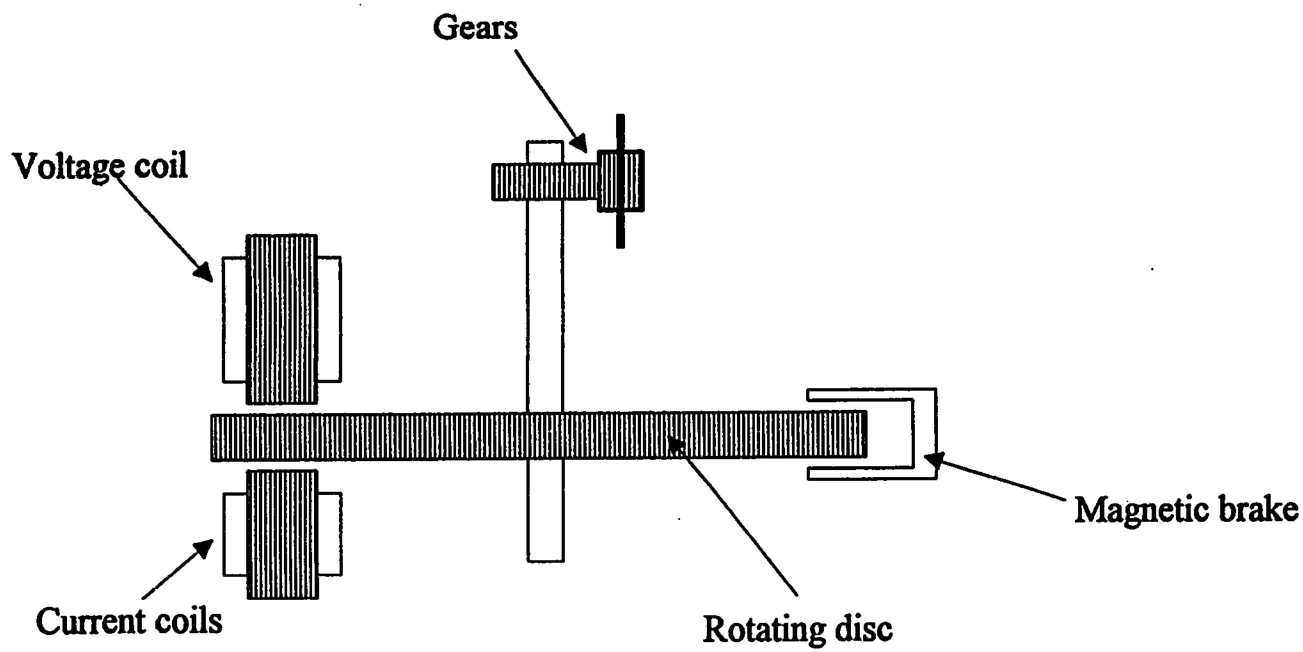

FIGURE 2.1, INDUCTION WATTMETER

SINGLE-PHASE

$$VI \cos\theta \tag{2.1}$$

where

V= Peak voltage

I= Peak Load current

$\cos\theta$= Load power factor

It should be noted that although frequency is absent from this expression for the torque on the disc, it will affect the induced eddy currents and hence the torque. Thus, the instrument is only suitable to use at its calibrated frequency.

Damping of the disc is provided by two small permanent magnets located opposite to each other at the rim of the disc. Whenever the disc rotates, the permanent magnets induce eddy currents in it. These eddy currents react with the magnetic fields of small permanent magnets, damping the motion of the disc.

Measurement of energy in three-phase systems are performed with polyphase watthour meters. Each phase of the watthour meter has its own magnetic circuit and its own disc, but all the discs are mounted on a common shaft. The developed torque on each disc is mechanically summed and the total number of revolutions per minute of the shaft is proportional to the total three-phase energy consumed [22].

Some properties of the induction watthour meters:

1. Satisfactory performance

The induction watthour meter is normally calibrated under conditions of full load and 10 percent of its rated power. Calibration of the meter at these two positions usually provides satisfactory readings at all other loads. The acceptable accuracy for the induction meters are given in the American National Standards (ANSI) Code for Electricity Metering [24].

2. Reliability

The induction meters lack sophistication, which makes their reliability virtually guaranteed.

Induction meters, in order to be acceptable, shall conform to certain requirements specified in sections

5.1.3 through 5.1.8 of the American National Standard (ANSI) Code for Electricity Metering. These standards are intended to determine their reliability and acceptable accuracy.

These meters perform their task satisfactorily, operate reliably, and have remained virtually unchanged for many years. Even today, induction meters are the dominant measurement device on power systems, and utilities continue to use and purchase them. However, there is a growing niche of applications where a more advanced device is needed. For example, the resolution for such meters is too poor to be interfaced to microprocessors or microcontrollers. Also, induction meters perform unsatisfactory when voltage/curent harmonics are present. This niche has fostered the development of the solid-state meter.

2.1.2 SOLID-STATE WATTHOUR METERS

Utilities are adapting solid-state meters to more applications, primarily because their price has gone down, reliability has increased, and maintenance and operating costs have decreased.

Some of properties of solid-state meters [12]:

1. Increased computing power

Solid-state meters can do more on-board processing, providing the utility with useful data rather than raw data.

2. Versatile communications

Solid-state meters support more communications media to serve a wider variety of applications.

3. Modularity

This allows a meter to be configured to suit a utility's specific needs.

The only drawback of solid-state meters is the lack of standards; however, efforts toward establishing standards continue, and industry meetings are still held regularly to discuss the issue.

In the following sections, the structure and operation of the solid-state meters are discussed. The most dominant solid-state meters are those based on digital sampling for the current and voltage.

2.1.2.1 SOLID-STATE WATTHOUR METERS USING ANALOG MULTIPLIERS TECHNIQUE

For simplicity, a single-phase power measurement using analog multipliers is presented. The instantaneous electric power consumed by a single-phase load with lagging power factor angle θ is given by [1]

$$\begin{aligned} p(t) &= v_s(t) i_s(t) = VI \sin(wt)\sin(wt-\theta) \\ &= \frac{VI}{2}[\cos\theta - \cos(2wt-\theta)] \end{aligned} \tag{2.2}$$

where

$v_s(t)$= Supply voltage
$i_s(t)$= Supply current
θ= Power factor (pf) angle
t = time

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$w=2\pi f$, f is the voltage and current frequency (60 or 50Hz).

Therefor, the real power varies about a mean value $\frac{VI}{2}\cos\theta$ at twice frequency because of the term $\frac{VI}{2}\cos(2wt-\theta)$. It is clear that the mean power into the load is

$$\frac{1}{T}\int_0^T v_s(t)i_s(t)dt=\hat{V}\hat{I}\cos\theta \qquad (2.3)$$

where $\hat{V}$, $\hat{I}$ are RMS values. It can be further shown that

$$v_s(t)i_s(t)=\hat{V}\hat{I}\cos\theta[1-\cos(2wt)]+\hat{V}\hat{I}\sin\theta[\sin(2wt)] \qquad (2.4)$$

where

$P=\hat{V}\hat{I}\cos\theta,\ Q=\hat{V}\hat{I}\sin\theta$

Therfore,

$$v_s(t)i_s(t)=P[1-\cos(2wt)]+Q\sin(2wt) \qquad (2.5)$$

Thus, the reactive power Q is the amplitude of the double frequency power oscillation.

These results show that the real power can be filtered using a low pass filter. Figure 2.2 shows the

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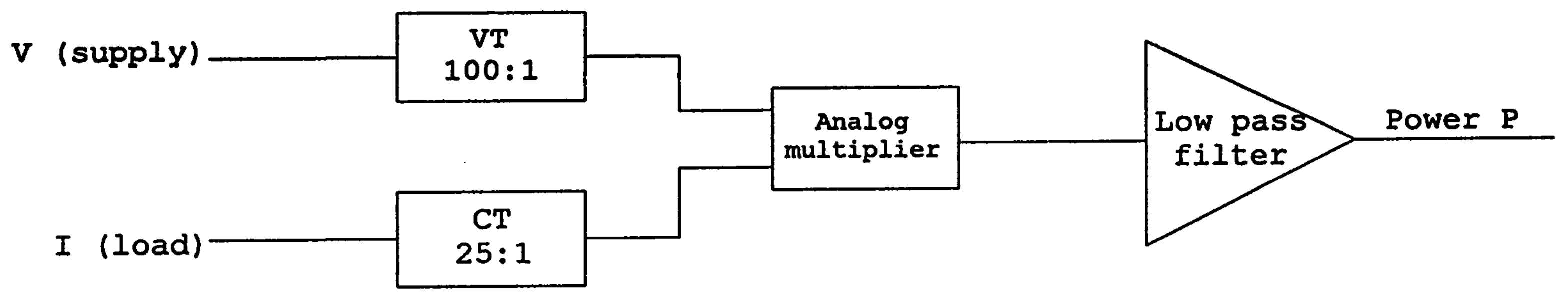

FIGURE 2.2
SINGLE-PHASE POWER MEASUREMENT

block diagram for a single-phase power measurement. This circuit can be interfaced easily to a microcontroller by using an analog to digital converter (A/D) as shown in Figure 2.3. Therefore, the energy is given by

for $t = t_0$ to t_1

$$W_P\Big|_{t_0}^{t_1} = \frac{(t_1 - t_0)}{N}\sum_{i=1}^{N} p_i \tag{2.6}$$

where

p_i= Instantaneous power

$N = \frac{f_P^{-1}}{\Delta T}$= Number of samples

f_P= Output power frequency (the frequency of the load changes)

ΔT= Sampling period

Watthour meters using analog multipliers techniques are fast for calculating the electric energy. However, analog multipliers have large errors (MC1495 multiplier have an error of ±4%) and are costly. Also, non sinusoidal current waves cause large errors or non ideal behavior in the circuit [1]. The power factor angle can not be calculated directly.

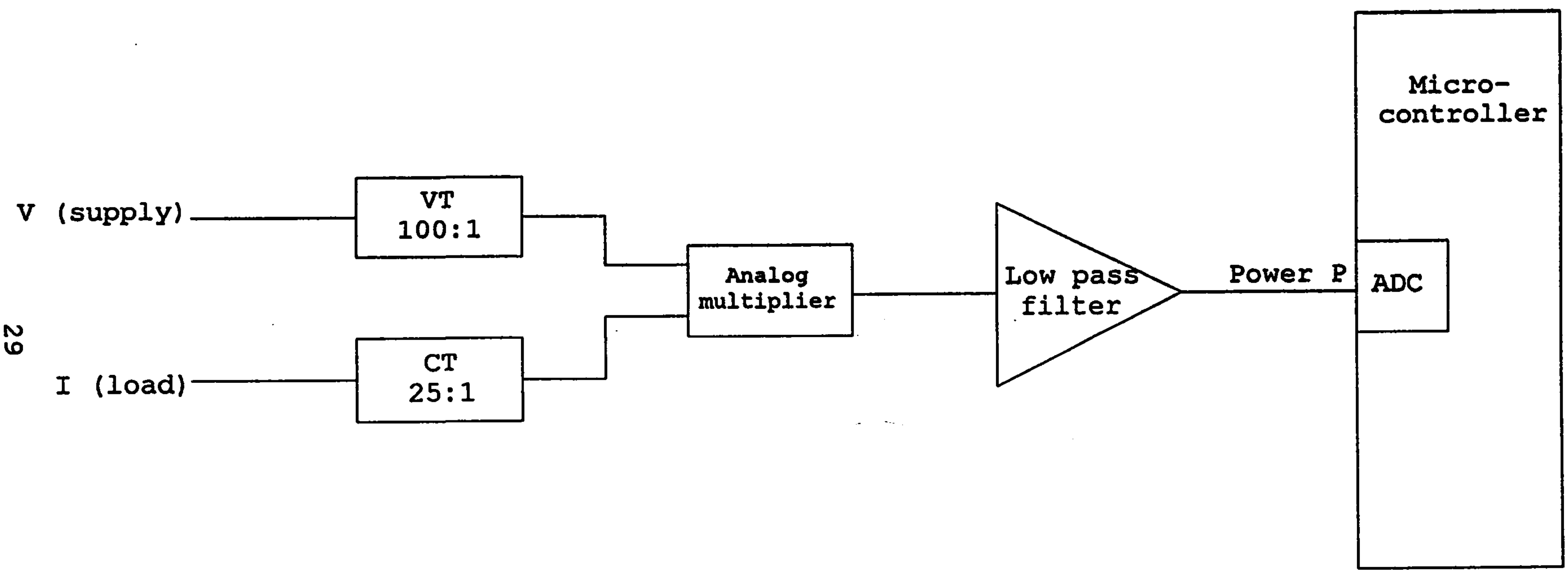

FIGURE 2.3
SINGLE-PHASE POWER MEASUREMENT
INTERFACED TO A MICROCONTROLLER

2.1.2.2 SOLID-STATE WATTHOUR METERS USING DIGITAL SAMPLING TECHNIQUE

The most common technique used in solid-state (digital) wattmeters or watthour meters is the digital sampling that is based on the utilization of microprocessors based system or microcontrollers.

The digital sampling wattmeter concept is pioneered by Turgel [18] and developed further by the National Physical Laboratory in the U.K. Power is measured by multiplying digitized samples of current and voltage waveforms.

The average power measured over an interval T is given by

$$P = \frac{1}{T}\int_0^T v_s(t)\,i_s(t)\,dt \qquad (2.7)$$

This Integral can be approximated by the summation

$$P = \frac{1}{N}\sum_{i=1}^{N} v_i i_i \qquad (2.8)$$

where

v_i= Instantaneous samples of voltage

i_i= Instantaneous samples of current

The samples are not required to be taken over a single period but can be spread over *m* periods (where *m* is an integer) allowing the sampling interval to be increased accordingly.

Two conditions are required to provide an accurate results [10]. The conditions required are:

1. The sampling must occur over an integral number of waveforms.

2. The waveforms are stationary for the duration of measurement.

The basic configuration of the digital sampling wattmeter is shown in Figure 2.4. The instrument is controlled by a single microprocessor. Signal conditioning boards for current and voltage are placed in a separately screened compartment to shield against the noise generated by the processor. The digitization is performed by two A/D converters, which are simultaneously triggered at a sampling interval previously determined by the processor. The samples

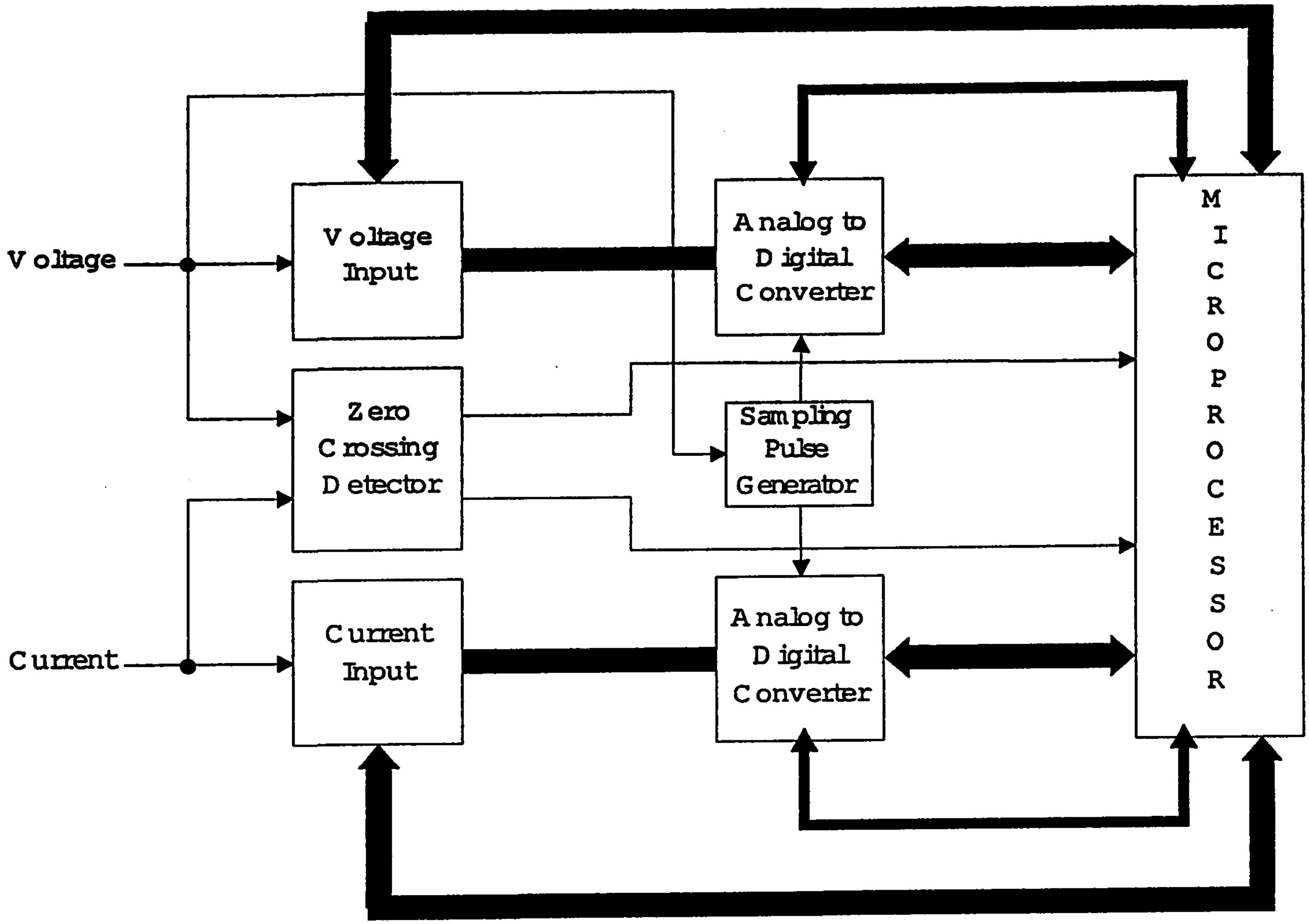

FIGURE 2.4, SIMPLIFIED DIGITAL SAMPLING WATTMETER

from each A/D converter are multiplied together and the products are summed and then averaged to obtain the power measurement. During data acquisition and subsequent processing, checks are made to ensure that the signals fall within the defined level and frequency limits.

There are different ways to calculate the required sampling period. One of these techniques, preferred in most of the references [10, 18, 19], is to measure the period between **m** successive positive-going zero crossings using the zero-crossing circuits shown in Figure 2.4. Then, the sampling period is given by

$$\Delta T=\frac{interval(m)}{N} \tag{2.9}$$

where

ΔT= Sampling period

m= number of cycles (positive zero-crossings) on which the period interval is measured

N= Number of samples required for one cycle

It was found that $N=29$ will achieve an acceptable accuracy [10, 19].

While the power measurement is of great interest to us, other functions can also be derived from the raw data. These are:

rms volts $\hat{V}=\left[\frac{1}{N}\sum_{i=1}^{N}v_n^2\right]^{1/2}$ (2.10)

rms amps $\hat{I}=\left[\frac{1}{N}\sum_{i=1}^{N}i_i^2\right]^{1/2}$ (2.11)

volt-amps $S=\hat{V}\hat{I}$ (2.12)

Reactive Power $Q=\left(S^2-P^2\right)^{1/2}$ (2.13)

Power factor $pf=P/S$ (2.14)

Phase angle $\theta=\tan^{-1}(Q/P)$ (2.15)

Frequency = $\frac{1}{T}$; where T is the wave form period.

The main advantage of the digital sampling technique is the measurement accuracy of the signals in the presence of harmonics. This technique is discussed in details in chapter 3.

2.1.2.3 SOLID-STATE WATTHOUR METERS USING ZERO-CROSSING TECHNIQUE

This method is mainly presented to provide a reasonable speed and accuracy without harmonics for calculating the electric real power. Also, the power factor angle is measured directly without the need of extensive processing by the processor. Furthermore, this method calculates the reactive power directly.

The general form for calculating the real power is given by

$$P = \frac{1}{2} VI \cos\theta \qquad (2.16)$$

The reactive power is given by

$$Q = \frac{1}{2} VI \sin\theta \qquad (2.17)$$

Three conditions are required to provide very accurate results. The required conditions are:

1. The sampling must occurs over an integral number of waveforms.

2. The waveforms are stationary for the duration of measurement.

3. No harmonics are present in the voltage and current waveforms.

The basic configuration of the zero-crossing wattmeter is shown in Figure 2.5.

This wattmeter consists of a peak detector circuits for the current and voltage. The power factor angle is measured by converting the sinusoidal voltage and current waveforms to square waveforms and then, fed to a zero-crossing circuit to extract the power factor angle. The real power is calculated by multiplying the RMS voltage and current with the cosine of the power factor angle.

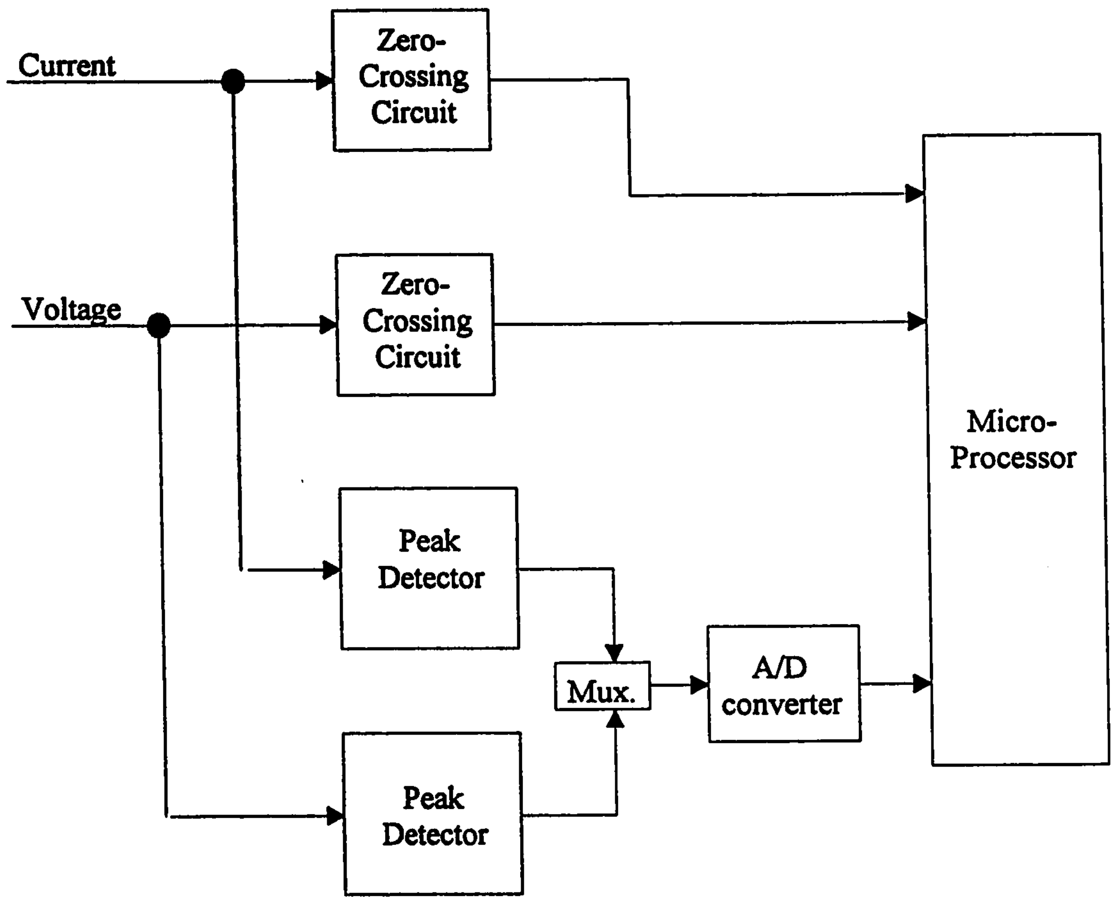

FIGURE 2.5, PROPOSED CIRCUIT CONFIGURATION FOR ZERO-CROSSING WATTMETER

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Since the voltage V and the current I are the peak values, they are not required to be sampled simultaneously. This reduces the number of A/D converters or sample-and-hold circuits from two to one only and the voltage and current signals are multiplexed for conversion.

This method requires only one sample for the voltage, current and power factor angle to be taken within m periods. The voltage and current samples should be taken at least after half a cycle to give enough time for the peak detector circuit to hold the peak value.

If the voltage or/and current frequencies are changed, the new frequencies can be measured using the power factor angle circuit. Measuring the power factor angle frequency will reflect the signals frequency. This will be discussed in chapter 3 in details.

2.1.3 EXISTING ENERGY BILLING METHOD

The billing method is shown in Figure 1.1 and discussed in Section 1.1. The energy consumption costs is given by

$$\text{Energy Costs} = (\text{Current KWH Record} - \text{Previous KWH Record}) \times \text{Rate} \quad (2.18)$$

The rate format varies from a company to another. As an example, the rate can have a fixed value for the first kwh's and different fixed value for the rest of the kwh's.

2.2 WATER/GAS FLOW METERS THEORY AND OPERATION

There are many different types of water/gas flow meters that are commercially available, based on a wide variety of operating principles. Each type of flow meter has strengths and weaknesses, and it requires skill to select the optimum meter for a particular application [24].

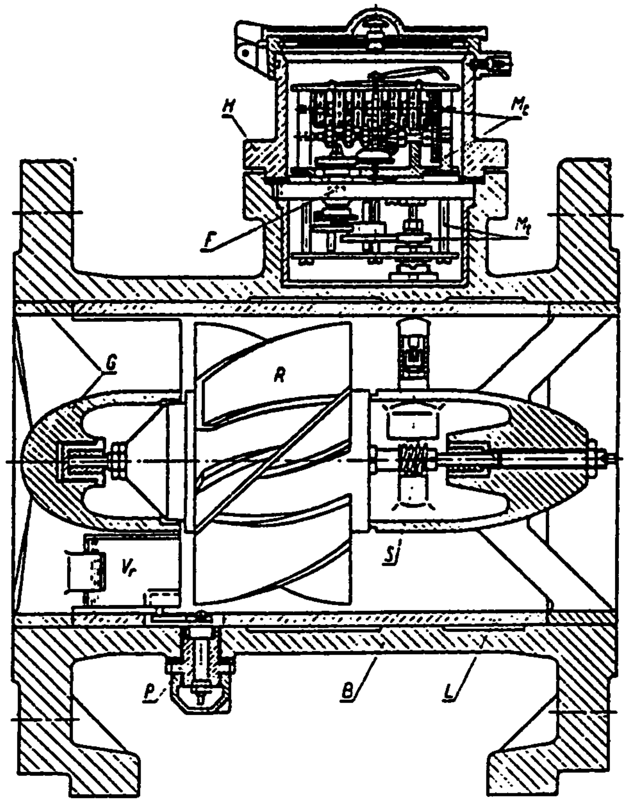
Currently, turbine flow meters are used by the water/gas utilities to register the customer's water/gas consumption for billing purposes. Turbine meters are preferable due to their output linearity as a function of the flow rate. Therefore, the concept of turbine flow meters, their types, properties, operation, and standards will be discussed.

2.2.1 MECHANICAL FLOW METERS

The mechanical flow meters are widely used in water/gas distribution system for water/gas consumption measurement. A typical design of a mechanical flow meter is shown in Figure 2.6 [25]. These meters are undesirable due to their low performance and calibration difficulties. A typical performance for a mechanical flow meter has a linearity of ±5. Furthermore, they are not compatible for interfacing with microprocessors or microcontrollers.

2.2.2 OPTICAL AND ELECTROMAGNETIC FLOW METERS

The basic construction of an optical or magnetic flow meter is shown in Figure 2.7 [25]. They consist of a multi-bladed rotor suspended in the fluid stream; the axis of rotation is parallel to the direction of flow. The fluid flow produces a force on the blades and causes them to rotate. The number of blades usually varies



B — body, F — stuffing box, G — straightening grid, H — counter box head, L — liner, M_c — counter mechanism, M_t — undergear, P — regulating pin, R — runner, S — worm-gear, V_r — regulating vane.

FIGURE 2.6, MECHANICAL FLOW METER

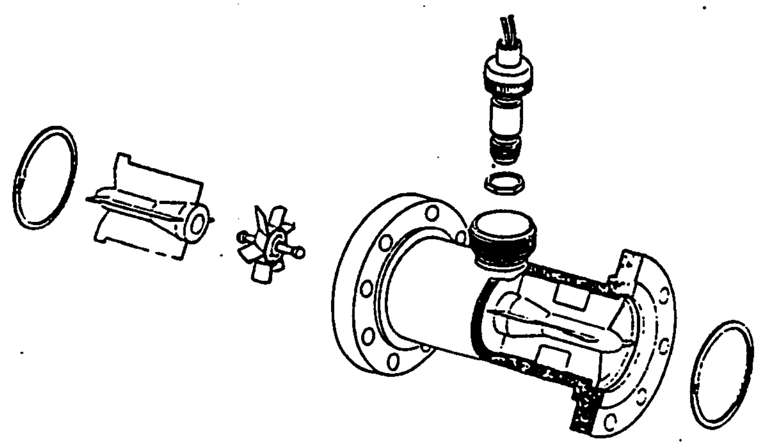


FIGURE 2.7, OPTICAL OR MAGNETIC FLOW METER

between four to eight. The rotation speed is monitored by either a magnetic or optical pick-off element, which senses the passage of the rotor blades [8, 26]. The number of cycles (rotations) per second f is proportional to the volume flow rate Q and given by

$$f = KQ \tag{2.19}$$

where

K= Meter factor constant

Therefore, the total fluid volume which has been delivered through the turbine meter during a time interval T is

$$N = \int_0^T f dt = K \int_0^T Q dt = KV \tag{2.20}$$

$$\Rightarrow V = \frac{N}{K}$$

where

V= Fluid volume

N= Number of cycles

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The meter factor K for a given flow meter is found by direct calibration. Typical results are shown in Figure 2.8. The normal flow range is usually from about 10% up to 100% of maximum rated flow. Over this range, the deviation of meter factor K from the average value is usually within ±0.5%. Below the 10%, the relation between the number of cycles (rotations) and the volume flow is non-linear [8, 26].

The normal optical and magnetic flow meters linearity is ±1.0 and ±0.5% at full scale deflection (FSD), respectively.

The advantages and disadvantages of turbine flow meters are outlined below [25, 26]. The general advantages are:

- Excellent short term repeatability.
- Digital output to indicated the flow rate, which is compatible with microcontroller or microprocessor.
- Excellent transient response.
- Compact design.
- Used for both liquids and gasses.
- Good reliability.

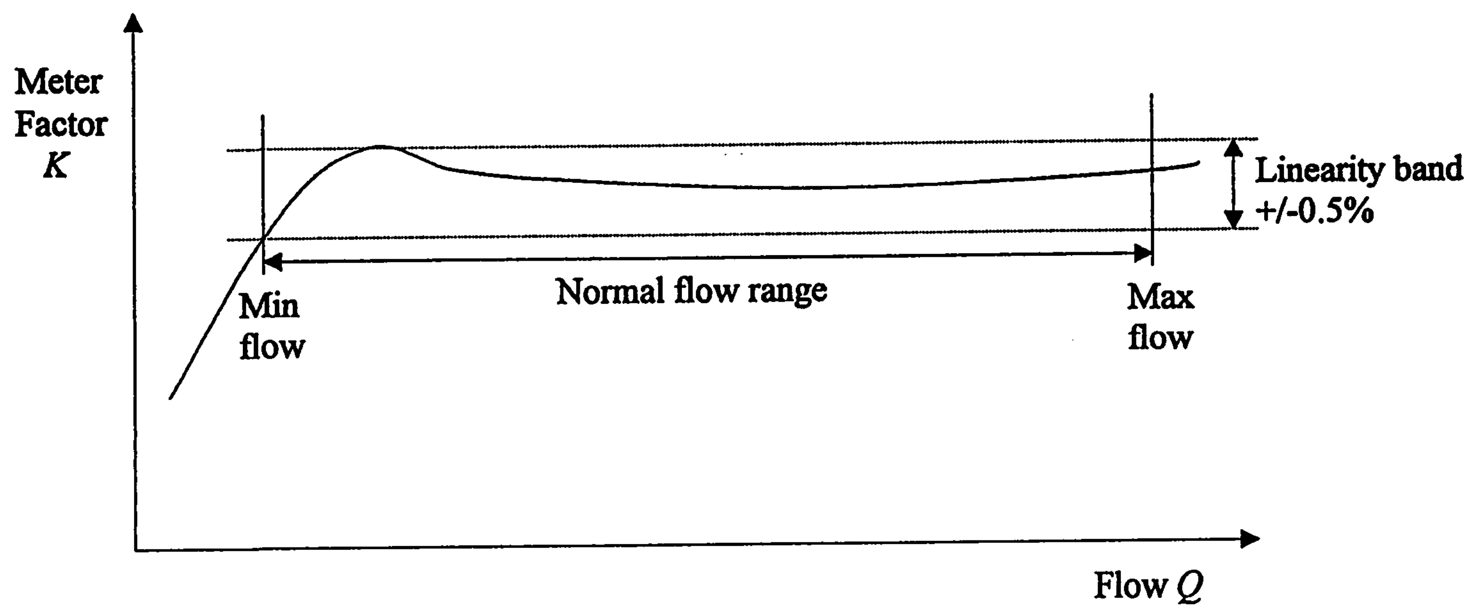

FIGURE 2.8, METER FACTOR CHARACTERISTICS

- Wide flow range and good linearity.
- Used over wide temperature and pressure ranges.

The general disadvantages are:

- Have to be calibrated periodically, due to component wear.
- Sensitive to viscosity and flow disturbance.

2.2.3 EXISTING WATER/GAS BILLING METHOD

The billing method is shown in Figure 1.1 and discussed in Section 1.1. The water/gas consumption costs are given by

Water/gas Consumption Costs =

(Current Water/gas Volume Record - Previous Water/gas Volume Record) × Rate (2.21)

The rate format varies from a company to another.

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2.3 TELEPHONE CALLS METERING PROCESS

Each subscriber telephone is connected to a central office that contains switching equipment, signaling equipment, and batteries that supply direct current to operate the telephone. Each phone is connected to the central office through a wire pair called a local loop. One of the wires is called T (for tip) and the other is called R (for ring) which refers to the tip and ring parts of the plug used in manual switchboards. Some of the modern digital switches, four wires are used. Two wires are used for the digitized voice signals and the other two are used for signaling.

Switches in the central office respond to the dial pulses, tones or digital signals from the telephone set, to connect the calling phone to the called phone. When the connection is established, the two telephones communicate over either transformer coupled loops using the current supplied by the central office batteries or time division multiplexing (TDM) using the pulse code modulation (PCM).

The call procedure between the call originator and the called phone is described in Appendix E.

2.3.1 SUBSCRIBER LINE INTERFACE CIRCUIT OR CARD (SLIC)

The SLIC is located in the digital switching system. It provides the interface circuits to connect a subscriber line to the digital switch and all of the BORSCHT functions. The BORSCHT stands for the functions of Battery feed, Over voltage protection, Ringing, Signaling, Coding, Hybrid, and Testing. Figure 2.9 shows the SLIC and BORSCHT block diagram [9].

Recently, a new SLIC consisting of two LSI chips has been reported. This SLIC can provide full coin telephone signaling functions as well as BORSCHT functions. The solid-state implementation of BORSCHT function and coin telephone signaling has achieved lower cost SLIC's, with less circuit board area and higher performance. Figure 2.10 shows the two chip for the new SLIC [29].

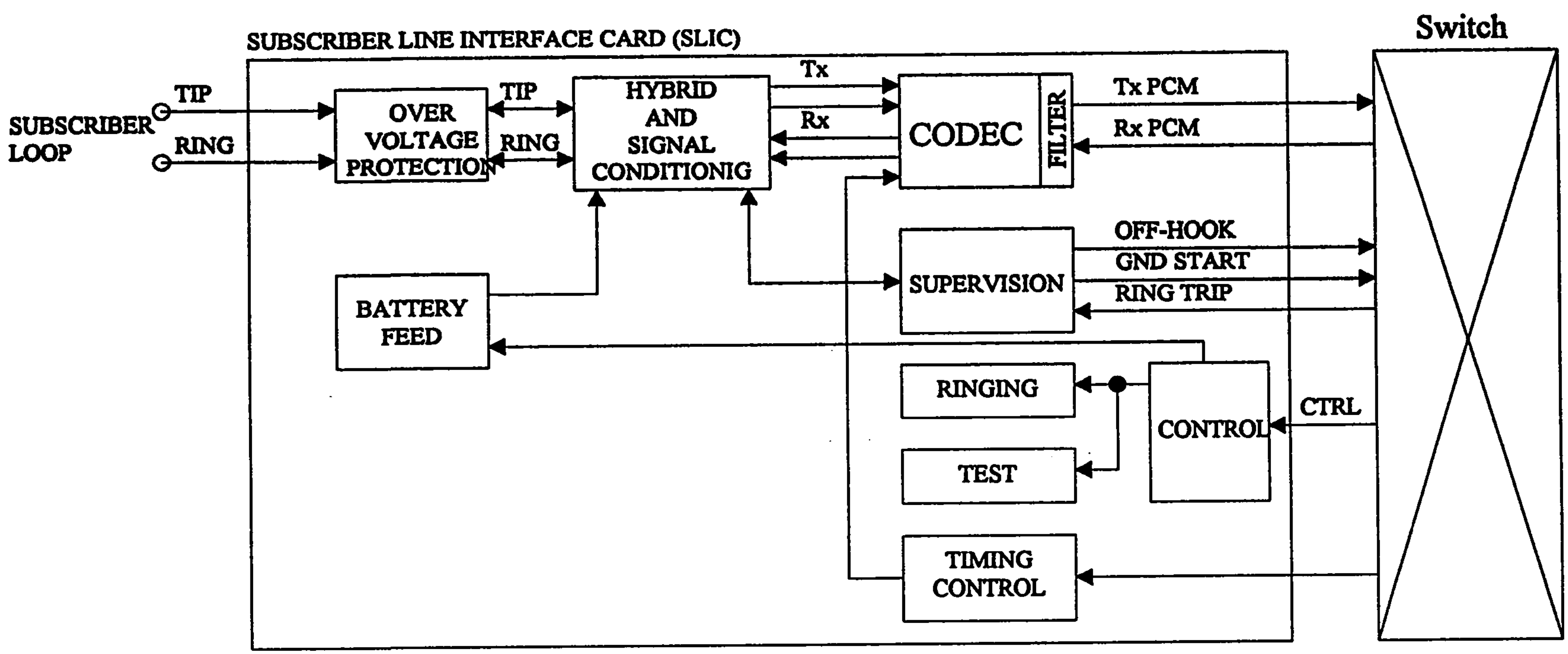

FIGURE 2.9, SLIC AND BORSCHT BLOCK DIAGRAM

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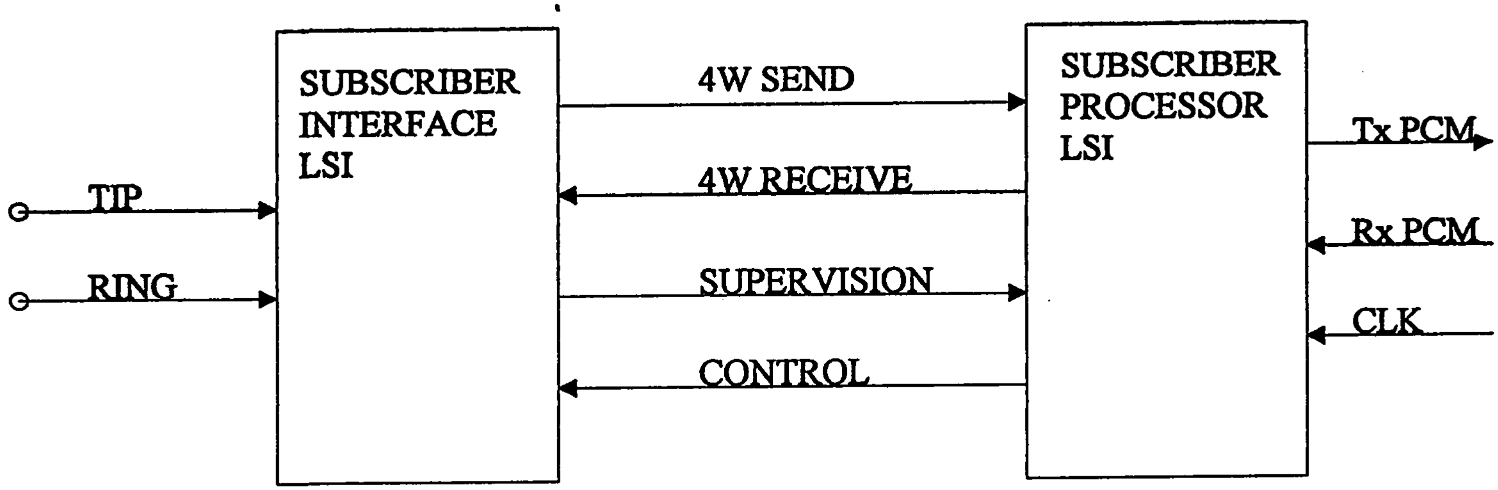

FIGURE 2.10, NEW SLIC CONFIGURATION

The two LSI IC's are:

- Subscriber interface IC: ringing, testing, battery feed and ringing.

- Subscriber processor IC: supervision, hybrid, codec, and control.

2.3.2 TOLL CALL INDICATION TECHNIQUES

Telephone toll call indications are important for charging. There are different ways to indicate that the call has been connected to the called party, so that charging for a toll call can begin.

2.3.2.1 PRIVATE PHONES

In private phones the toll call can be detected through either circuit interruption (removing the battery) or reversing the battery of the tip-ring pair. However, in most modern switches the toll call can be detected via digital signaling (out of band signaling). This means that the answer supervision signals cannot be

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detected at the calling party. The billing mechanism for the private phone is discussed in section 1.1 and shown in Figure 1.2. The call start time, stop time, the caller number, and the called number are recorded on a tape. A data base ,of Country and City Access Codes and the associated Call Charge Rates, is used to find the call charge rate from the called number. Therefore, the call charge is given by

$$\text{Call Charge} = (\text{Stop Time} - \text{Start Time}) \times \text{Rate} \quad (2.22)$$

2.3.2.2 PUBLIC PHONES (COIN PHONES OR CREDIT CARD PHONES)

Public phones receive pulses every period of time (i.e. one minute) to charge the caller for that period. These pulses are generated via a separate circuit in addition to the SLIC. Several researches were directed toward a new subscriber line interface circuit to integrate the BORSCHT functions and Coin Telephone Signaling Facilities [29].

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2.4 MAGNETIC CARDS

The electronic magnetic card as a transactional medium is an old idea that appeared in a number of articles and patents over the years, but it was given an important boost in the early 1970s by a French inventor, Roland Moreno [15].

Magnetic Card is a piece of plastic measuring 8.6 by 5.4 by 0.08 cm [36] which has an encoded magnetic stripe on one side. The stripe contains information in a coded format that can only be decoded by a microcomputer in a card reader that has the code format. The magnetic stripe can be divided into three main sections or tracks to suit most of the application. The three tracks are [36]: Track 1 is read only memory and used for alphanumeric data, Track 2 is, also, read only memory and used for numeric data, and Track 3 is read/write memory and used for numeric data. Furthermore, each section or track is subdivided to suit specific application [15, 20].

Prepayment cards have specific usage value magnetically, in a decimal cash or in units, imprinted on them that is erased after use. The stored usage value could include a security-related access code to prevent the card from being used in an improper manner and to protect the controlled system (card reader). The prepayment cards replace coins in telephones, and also used for subway tickets, postage stamps, movie tickets, expressway tolls, gas stations, and supermarket shopping. The cards value are read on site by a card reader.

The disadvantage of the magnetic credit-cards is insecurity. Simple magnetic stipe credit-cards can be easily duplicated. This problem can be resolved by utilizing the most recent technology in credit cards which is smart cards. The term 'smart' card is used to describe a data processor and storage (memory) device packaged in the format of a credit card [15,41].

2.5 EXISTING METERING AUTOMATION SYSTEMS

In this section, two of the systems that attempted to automate the billing systems for the public utilities are discussed.

2.5.1 A MICROPROCESSOR-BASED SYSTEM FOR THE IMPLEMENTATION OF VARIABLE SPOT PRICING OF ELECTRICITY.

This system was reported in 1990 [2]. The basic functions of the system are summarized below:

- Provides a variable rate schedule for the cost of electricity as a function of time at each house.
- Provides means of allowing the customer to vary consumption of electricity automatically as a function of price.
- Provides means of registering the usage of electricity at a given price.
- Provides means of timely bi-directional communication of relevant information.

The System configuration is shown in Figure 2.11. The data to and from the System Manager is transmitted over an X.25 packet network operating over a communication link to remote sites through central offices. The average phone call lasts 30 seconds. The customer's equipment is also capable of initiating a phone call to

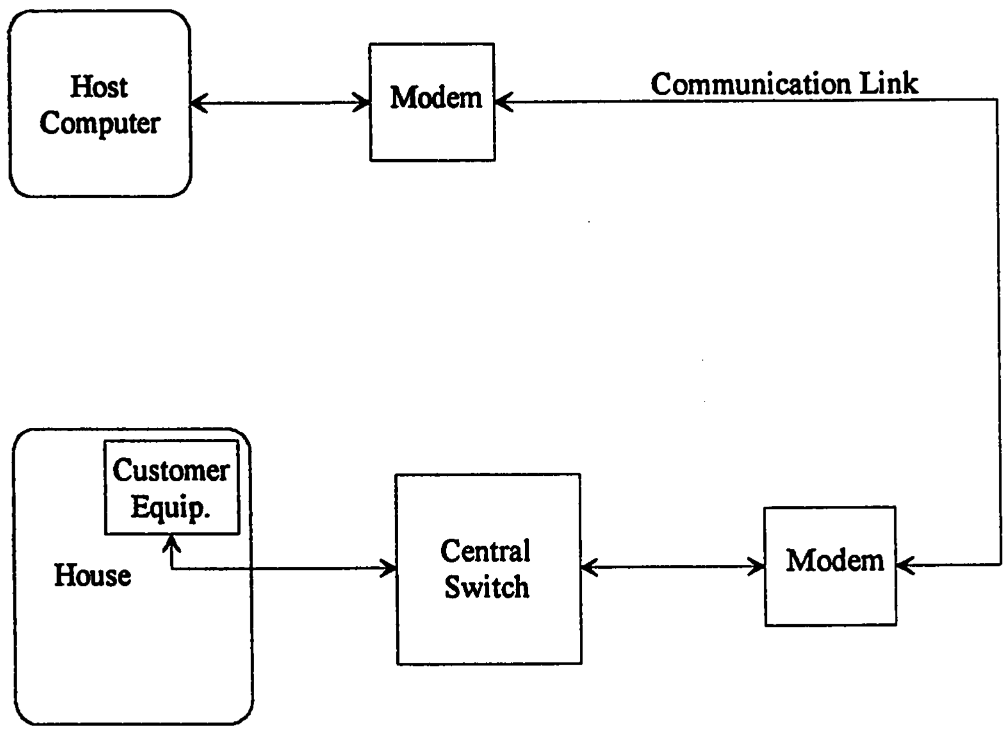

Figure 2.11

Communication System Configuration

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report information either on a scheduled basis or on demand.

The final link of the system is the equipment located at the customer's house. This equipment consists of a smart modem, an electronic meter, a heating, ventilating, air conditioning (HVAC) controller, programmable thermostat, and an electric water/gas heater relay. The concept behind the customer's equipment is to moderate home environment, automatically, through energy management as a function of price.

System Advantages:

- Eliminates human errors.
- Speed-up Billing process.
- Provides data analysis.
- Provides load management.
- Uses solid state meter.
- Provides a variable rate schedule for electricity cost as a function of time at each house.

- Provides means of allowing the customer to automatically vary the consumption of electricity as a function of price.

System Disadvantages:

- Sending the statements to customers by mail or via the company personnel.
- Statements are generated periodically.
- The system is very complicated.
- The number of houses is limited.
- This system is used only for Electricity Billing.
- The system is costly.
- Before the statement, the customer does not know the charges.
- The metering depends on the customer's telephone line, which may fail any time or does not exists.

2.5.2 ENERGY MANAGEMENT UNIT (EMU)

This system was reported in 1990 [27]. The basic system configuration is shown in Figure 2.12. The main part of the system is the EMU electronic meter for the electricity measurement, which can also accept pulses

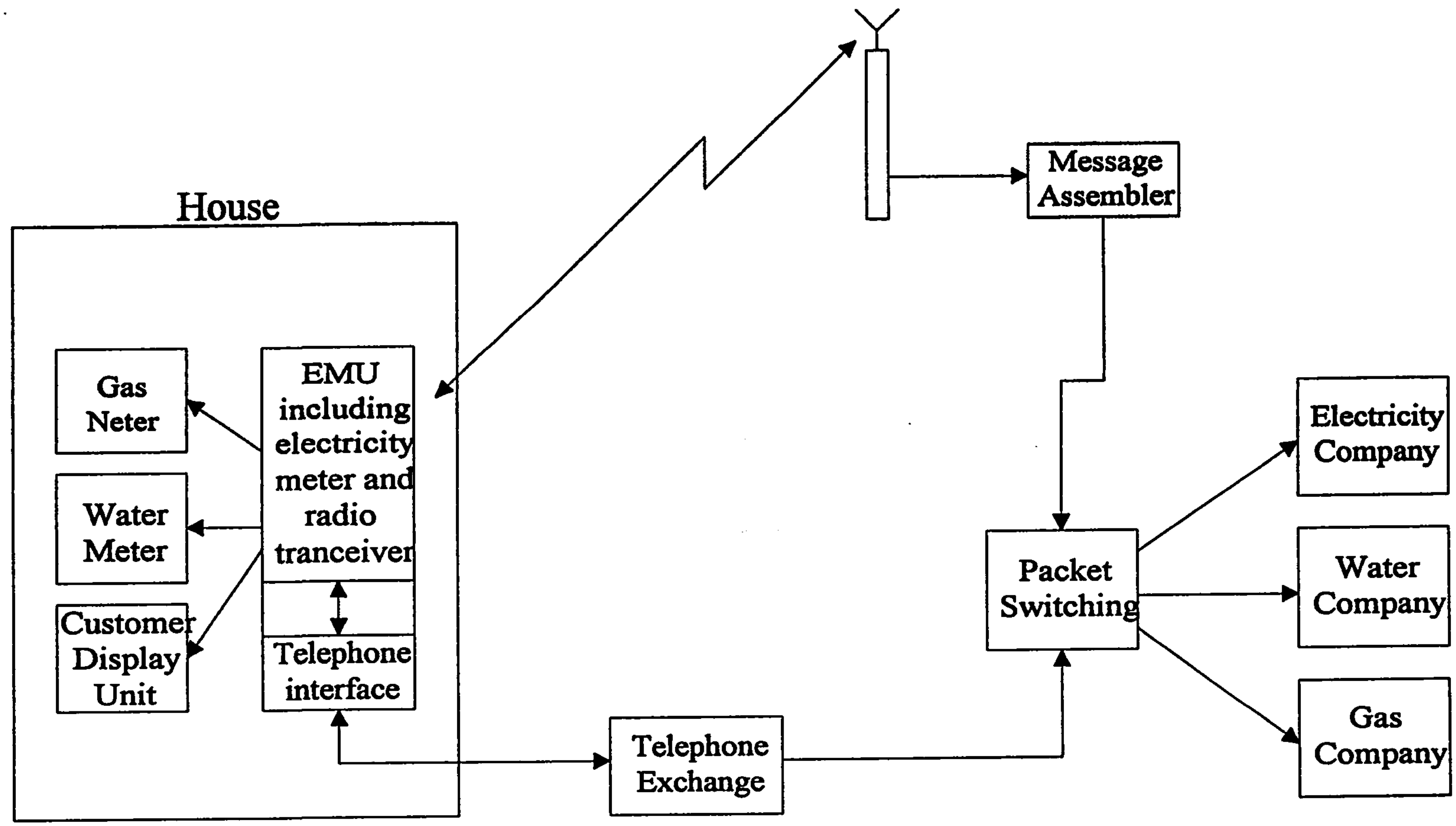

FIGURE 2.12
ENERGY MANAGEMENT UNIT SYSTEM

from gas and water/gas meters. An important part of the EMU is the separate Customer Display Unit (DCU) which displays metering (including gas and water/gas) as well as other information. Communications with the meter is possible by means of Radio or Telephone lines.

System Advantages:

- Eliminates human errors.
- Speed-up Billing process.
- Provides data analysis.
- Provides load management.
- Uses solid state register (Digital Meter).
- Provides a variable rate schedule for electricity cost as a function of time at each house.
- Provides means of allowing the customer to monitor his consumption.
- The system can also be used for gas and water/gas.

System Disadvantages:

- Sending the Statements to customers by mail or via the company personnel.
- Statements are generated periodically.

- The system is very complicated.
- The number of houses is limited.
- This system can be used for telephone Billing.
- The system is costly.
- The metering depends on the customer's telephone line or Radio network, which may fail any time or does not exists.

SUMMARY

In this chapter, it has been found that the digital wattmeters offer major advantages over conventional (induction) wattmeters. Also, the electronic (optical or magnetic) turbine flow meters are very attractive for water/gas metering. Furthermore, telephone calls can be remotely charged, using different type of answering supervision detection techniques. Moreover, the magnetic prepayment card concept has proven satisfactory acceptance by the users in different type of applications.

CHAPTER 3

PROPOSED ENERGY, WATER/GAS, AND TELEPHONE CALLS METERING AND BILLING TECHNIQUES

In this chapter, the proposed Energy, Water/Gas, and Telephone calls metering techniques are presented. Furthermore, the proposed billing methods for each metering system is presented. Then, the microcontroller structure that suits the proposed system is specified and selected.

3.1 PROPOSED ENERGY METERING METHOD

From Chapter 2, it appears that solid-state wattmeter, specifically the ones that adopt the digital sampling and the zero-crossing techniques, are highly applicable to the proposed system. Therefore, the performance of these two wattmeters are, thoroughly, analyzed by a simulation program. It was found that, if no harmonics are present, the zero-crossing technique is highly applicable to the proposed system. However, if harmonics are present, the digital sampling technique is highly recommended.

A simulation program is developed for the two techniques, mainly, to determine the performance under different types of parameters to suit the application. Also, the simulation goal is to find out the effects of the sampling period on the power measurement accuracy. The study took into account the effects of the presence of harmonics. However, the study did not take into account the effect of the A/D converters resolution, since they are common for the two techniques.

3.1.1 DIGITAL SAMPLING WATTMETER SIMULATION PROGRAM

The simulation program is developed based on the two conditions mentioned in Section 2.1.2.2.

CASE I: ASSUMING NO HARMONICS ARE PRESENT IN THE SIGNALS

In this case, it is assumed that no harmonics are present in either the voltage and current waveforms. The developed program is provided in Appendix A. The samples are spread over m cycles to increase the sampling interval. The chosen number of cycles is $m=7$ and number of samples is $N=29$ as suggested by references [10, 19]. The waveform frequency is chosen to be $f=60Hz$. The results under different parameters are tabulated in Table 3.1.

Signal period $T(10^{-3}Sec.)$	# of Cycles m	# of Samples N	Sampling period $\Delta T(10^{-3}Sec.)$	Sampling delay $(10^{-3}Sec.)$	Error %
16.67	7	29	4.0	0	0.326
//	//	//	4.02	//	0.068
//	//	//	4.023	//	2.739×10^{-4}
//	//	20	5.8	//	0.592
//	//	//	5.833	//	0.023
//	//	//	5.8333	//	1.881×10^{-4}
//	//	29	4.023	0.1	2.105

Table 3.1

Case I.1: Sampling Precision

The sampling period is given by

$$\Delta T=\frac{mT}{N}=\frac{7*60^{-1}}{29}=4.0\times10^{-3}Sec. \tag{3.1}$$

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Executing the simulation program with this sampling period, gives us an error of 0.326 percent. However, if more significant digits are carried (i.e. the sampling period is to be taken $\Delta T = 4.02 \times 10^{-3}\,Sec.$), the error is reduced as shown in the table. As a result, this method requires a very precise sampling pulse trigger generator.

CASE I.2: Samples Number and Sampling Period Precision

If the number of samples are reduced from $N = 29$ to $N = 20$ for the same number of cycles $m = 7$, the sampling period is given by

$$\Delta T = \frac{7 * 60^{-1}}{20} = 5.8 \times 10^{-3}\,Sec.$$

Executing the simulation program with this sampling period, gives us an error of 0.592 percent. If the program is executed with the same parameters but the sampling period carries more significant digits (i.e. to be taken $\Delta T = 5.833 \times 10^{-3}\,Sec.$), the error is reduced as shown in the table.

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Therefore, with $N<29$ and very precise sampling period, the accuracy for $N=29$ could be achieved.

Based on the Nyquist theorem, the sampling frequency is given by

$$f_s \geq 2f \tag{3.2}$$

where

$f=$ Voltage or current frequency

For $f=60Hz$

$\Rightarrow f_s \geq 2\times 60 = 120Hz$

f_s could be chosen $240Hz$

$$\Rightarrow N=\frac{240}{60}=4$$

$$\Delta T=\frac{mT}{N}=\frac{7*60^{-1}}{4}=29.0\times 10^{-3}Sec.$$

where

$m=$ Number of cycles

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If the program is executed with the above sampling period, the error is 2.366 percent. However, if the program is executed with more precise sampling period of $\Delta T = 29.2 \times 10^{-3} Sec.$, the error is 0.772 percent. Further, with very precise sampling period of 29.1667×10^{-3}, the error is 7.257×10^{-4} percent. Therefore, with $N = 4$ and a very precise sampling period, the accuracy for $N = 29$ could be achieve . However, the number of samples $N = 29$ was chosen to provide stability measurement and simplify the sampling pulse generator circuit that is used to trigger the A/D converters.

CASE I.3: Current and Voltage Sampling Delay

In the above simulation, it was assumed that both current and voltage signals are sampled simultaneously. Now, the sampling technique with a delay between the current samples and voltage samples is examined.

The program, provided in Appendix A, is executed with $N = 29$, $m = 7$, $\Delta T = 4.023 mS$, $Delay = 100 \mu S$. The error is found

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out to be 2.105 percent. Previously, with no delay, the error was 2.739×10^{-4} percent.

Therefore, the sampling technique requires that both current and voltage to be sampled simultaneously. This can be achieved by providing two A/D converters triggered at the same time for conversion or two sample and hold circuits, one analog multiplexer and one A/D converter.

A question that may arise at this point, is why not the sampling period is set constant in such a way that it accommodates the required maximum frequency and this will result in deleting the sampling pulse generator. There are many reasons for not doing so, Below are some of them:

1. The maximum frequency is unknown; however, the maximum frequency could be limited.

2. In order to support high frequency, the sampling period will be very small which will result in a large number of samples for low frequency signals.

3. At low frequency signals, the system will be more sensitive to noise.

4. It requires extensive calculations for evaluating the functions.

CASE II: HARMONICS EFFECT ON THE DIGITAL SAMPLING TECHNIQUE

Now, consider the case where the voltage and current waveforms both have harmonics present. The voltage waveform may be expressed as

$$v_s(t) = \sum V_n \sin(nwt + \theta_n) \tag{3.3}$$

where

V_n= Amplitude of harmonic voltage

n= Harmonic order

θ_n= Phase angle of the harmonic

The current waveform may be expressed as

$$i_s(t) = \sum I_n \sin(nwt + \phi_n) \tag{3.4}$$

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where

I_n= Amplitude of harmonic current

n= Harmonic order

ϕ_n= Phase angle of the harmonic

Assuming the voltage consists simply of the fundamental and the load current consists of several harmonics, the real power is given by

$$P = \frac{1}{T}\int_0^T V\sin(wt)\sum I_n \sin(nwt + \theta_n)dt \qquad (3.5)$$

Using digital sampling technique, it is possible to measure the real power including the harmonics effects. The simulation, for measuring the real power in the presence of harmonics, is provided in Appendix A. The results for different number of samples are tabulated in Table 3.2.

Signal period $T(10^{-3}Sec.)$	# of Cycles m	# of Samples N	Sampling period $\Delta T(10^{-3}Sec.)$	Sampling delay $(10^{-3}Sec.)$	Error %
16.67	1	29	0.575	0	2.79×10^{-8}
//	//	12	1.389	//	10.14
//	//	3	5.557	//	18.16

Table 3.2

From the above table, it is concluded that the number of samples should be large enough to accommodate the harmonics.

3.1.2 ZERO-CROSSING WATTMETER SIMULATION PROGRAM

The simulation is based on the three conditions mentioned in Section 2.1.2.3.

The simulation program is provided in Appendix A with $m=7$, $f=60Hz$.

Based on these parameters one sample is required every 0.1167 Sec. ($\Delta T = mT = 7*60^{-1} = 0.1167 Sec.$)

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The error is Zero!; the only error source will be the A/D resolution, circuits inherited errors, and if any of the three conditions is not satisfied.

On the other hand, if the load current contained harmonics, the error increases. As an example, if the load current contained harmonics up to the eleventh with values as shown in Appendix A, the error is 12%.

3.1.3 COMPARISON BETWEEN THE DIGITAL SAMPLING AND ZERO-CROSSING TECHNIQUES

Based on the simulation results and circuits configuration, discussed in Cahpter 2, for the two techniques, Table 3.3 summarizes the results and conclusions on which the recommended technique will be used in the proposed system.

	Method I Digital Sampling Wattmeter	Method II Zero-crossing Wattmeter
Circuit configuration	See Figure 2.1. • 2-A/D convert • 2-Zero crossing circuits. • Sampling pulse generator. (1-counters, 1-sinusoidal to square wave converters, 1-mux, Gates, etc.). • Microcomputer.	See Figure 2.2. • 1-A/D convert. and 1-mux. • 2-zero crossing circuit used for pf and sampling period (2-sinusoidal to square wave converters, Gate). • 2-peak detectors. • Microcomputer.
Circuit complexity[1]	More	Less
Power consumption[1]	More	Less
Number of samples required	At least 3 samples[2]; however the recommended is 29 samples[2].	One sample.[3]
Power factor angle	Requires extensive calculation.	Requires few calculation.
rms voltage	To be calculated using equation.	Measured divided by square root of 2.
rms current	To be calculated using equation.	Measured divided by square root of 2.
Real power calculation	To be calculated using equation.	To be calculated using equation.
Reactive power calculation	To be calculated using equation.	To be calculated using equation.
V & I samples delay	Dependent (error increases as delay increases).	Independent (as long as the readings are taken within the m cycles).

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Major source of errors	• A/D converters resolution. • Sampling pulse accuracy. • Sampling delay.	• A/D converter resolution. • Harmonics
Accuracy	• Accurate in both cases of harmonics and no harmonics.[5]	• Very accurate in the case of no harmonics. • Poor in the case of harmonics.
Software considerations	• Requires coordination between the sampling pulse generator hardware and software samples readings. • Requires extensive calculation for the required functions. • Requires more memory for samples.	• Does not require any coordination; the sampling period is generated by software. • Simple calculation for the required functions. • Does not require memory for samples, only one sample.
High frequency signals	Supported by the sampling pulse generator circuit.	supported by the zero-crossing circuit.
Costs[4]	More	Less

Table 3.3

Notes:

1. Based on the number and type of components.
2. Includes two readings: current and voltage.
3. Includes three readings: current, voltage and pf angle.

4. Includes hardware and software costs.

5. Number of samples should be > 3.

Based on the above table, the real power calculation and related functions in the presence of no harmonics using the Zero-crossing technique is faster, simpler and more practical than the Digital Sampling technique. However, the digital sampling technique is very effective for calculating the real power in the presence of harmonics.

Thus, the two versions of power measurement will be designed. The first one is based on the zero-crossing technique to be used in the cases, where it could be assumed that no harmonics present in the voltage and current waves; as an example for residential applications. The second one is based on the digital sampling technique to be used in the cases, where harmonics present in the voltage and current waves; as an example for industrial applications.

3.1.4 BILLING METHOD

Consumers are charged for the electrical energy. The energy for a period of (mT), using the digital sampling technique, is given by

$$W_P = \int_{t_0}^{mT} v_s(t) i_s(t) dt \qquad (3.6)$$

This can be approximated by the summation

$$W_P(watt \cdot \sec) = \Delta T \sum_{i=1}^{N} v_i i_i \qquad (3.7)$$

For the zero-crossing technique, the energy is given by

$$W_P = \frac{mT}{2} VI \cos(\theta) \qquad (3.8)$$

Thus, the consumed energy costs is calculated by

$$\text{Energy Cost} = W_P \times \frac{1H}{3600Sec} \times \frac{1KWH}{1000watt} \times Rate \qquad (3.9)$$

$Rate$ = Price for KWH

3.2 PROPOSED WATER/GAS METERING METHOD

Currently, in most of the water/gas distribution systems, mechanical recording meters are used for water/gas consumption measurement. In Chapter 2, it was seen that these mechanical meters have poor performance. Also, the advantages of the magnetic flow meters over the existing one have been discusseds.

Therefore, a magnetic flow meter will be used in the proposed system in water/gas metering to achieve the required accuracy.

3.2.1 BILLING METHOD

The water/gas consumption for a period of time (T) is given by

$$\text{Water Consumption } = \int_{t_0}^{T} Q(t)dt \qquad (3.10)$$

This can be approximated by the summation

$$\text{Water Consumption } (litre/\min) = \Delta T(\min)\sum_{i=1}^{N} Q_i \qquad (3.11)$$

Q_i= Instantaneous water/gas volume rate

Thus, the consumed water/gas costs is calculated by

$$\text{Water Cost} = \textit{Water Consumption} \times \frac{1\textit{kgallon}}{1000 \times 3.78\textit{litre}} \times \textit{Rate} \qquad (3.12)$$

$\textit{Rate}$ = Price for $1\textit{kgallon}$

3.3 PROPOSED TELEPHONE CALLS METERING METHOD

It was found out, in Chapter 2, that there are two ways to charge the customer without the need of the central office. These are:

- Detecting the battery interruption or polarity reversal. This technique requires detection of the country and area/city code that is dialed by the customer. A data base of country, area/city, and call rates are also required. Beforehand, it is required to identify the method used for supervision (battery interruption or reversing the battery polarities). This technique is discussed in details in Chapter 5.

- Detecting the coin control pulse. The speed of the pulses indicates the call rate. This technique does not require any type of processing other than sensing the control pulse. This technique is discussed in details in Chapter 4.

In most of the cases, the first technique is not valid. This is because, the supervision signal is not always available at the customer loop. Also, this technique is complicated and requires a large memory to store the data base, which requires an update from time to time.

Therefore, since the second technique does not require any data base, the knowledge of the switch type, and very simple to process, the second technique is highly applicable for the proposed system and will be adopted.

3.3.1 BILLING METHOD

The telephone call charge for a period of time (t_0 to t_1) is given by

$$\text{Telephone Call Charge} = R \times rate \tag{3.13}$$

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where

$$R = \frac{Call\,Duration\,(t_1 - t_0)}{Pulse\,Speed}$$ Number of pulses for a call

rate= Number of units per pulse (fixed)

3.4 MICROCONTROLLER STRUCTURE

The microcontroller structure that will suit the proposed system should satisfy the following specifications:

- CPU is a 16-bit ALU.
- 64 Kbyte memory addressing.
- Multi-channel 16-Bit timer system.
- EEPROM for system parameters and data saving.
- EPROM for program.
- Ram for temporary data saving.
- Multi Real-time interrupt circuits.
- Multi-channel A/D converters.
- Bi-directional I/O ports.
- Serial port.
- All on a single chip.

The minimum number of I/O's, timers, interrupts, A/D converters will be specified during system design.

SUMMARY

In this chapter, it is concluded that either the digital sampling or the zero-crossing technique, depending on the presence of harmonics, can be used for measuring the energy. Also, it was found out that the magnetic turbine flow meters are very suitable for water/gas metering. Furthermore, it was seen that telephone calls can be remotely charged, using the coin control pulse detection technique. This method is highly applicable for the proposed system. Moreover, the magnetic prepayment card concept is very suitable for the proposed system for billing. Finally, the specifications of the microcontroller have been defined.

CHAPTER 4

THE PROPOSED SYSTEM:

HARDWARE DESIGN & SOFTWARE ALGORITHMS

In this chapter, the hardware design and software algorithms for the proposed system are presented. The hardware structure consists of an energy, a telephone call, a water/gas mater, and their control circuits which are discussed in details. Then, the proposed magnetic card memory format is discussed, followed by an integrated system of these circuits with an alarm circuit, and a microcontroller and its utilization are explained. Finally, the software algorithms are developed for each meter.

4.1 HARDWARE DESIGN

This section is devoted for the proposed system hardware design. First, the design parameters are presented. Then, the design of each meter circuit and microcontroller interface are discussed. After that, these circuits are integrated to form the proposed system.

4.1.1 DESIGN PARAMETERS

Various design parameters are assumed in the proposed system design. Following are descriptions of the main parameters considered:

1. All meters are interrupt driven.

2. A three phase feeder is assumed to be connected to the system.

3. The telephone call charge control pulse is assumed to be provided by the central office.

4. The number of telephone lines is assumed to be one.

5. The number of water/gas service is assumed to be one.

4.2 ENERGY METER CIRCUIT DESIGN

In this section, the zero-crossing and digital sampling wattmeters will be designed to suit the application. The zero-crossing technique will be used, if it is assumed no harmonics are present in the signals. However, the digital sampling technique can be used in all cases.

4.2.1 ZERO-CROSSING WATTMETER CIRCUIT

A hardware design that implement the zero-crossing technique for measuring the energy consumption is presented along its direct interface circuit with a microcontroller. The zero-crossing wattmeter block diagram for one phase feeder is shown in Figure 4.1. The wattmeter configuration is composed of a current transformer (CT) which is used to reduce the load current to a low level. A parallel low value resistor is required at the secondary to convert the current to voltage signals. A voltage transformer (VT) is also required to reduce the primary voltage to be compatible with the microcontroller. The outputs from the CT and the VT are fed to a current and a voltage peak detector circuits from which the outputs are passed to a multi-channel A/D converter. Also, the sinusoidal waves from the CT and the VT are converted to square waves using two comparator circuits. These square waves are, then, passed to an exclusive OR (XOR) gate to produce a pulse that corresponds to the phase angle between the load current and the voltage source (see Figure 4.2). The pulse width (T_{XOR}) can be utilized to compute the power factor angle using the following equation:

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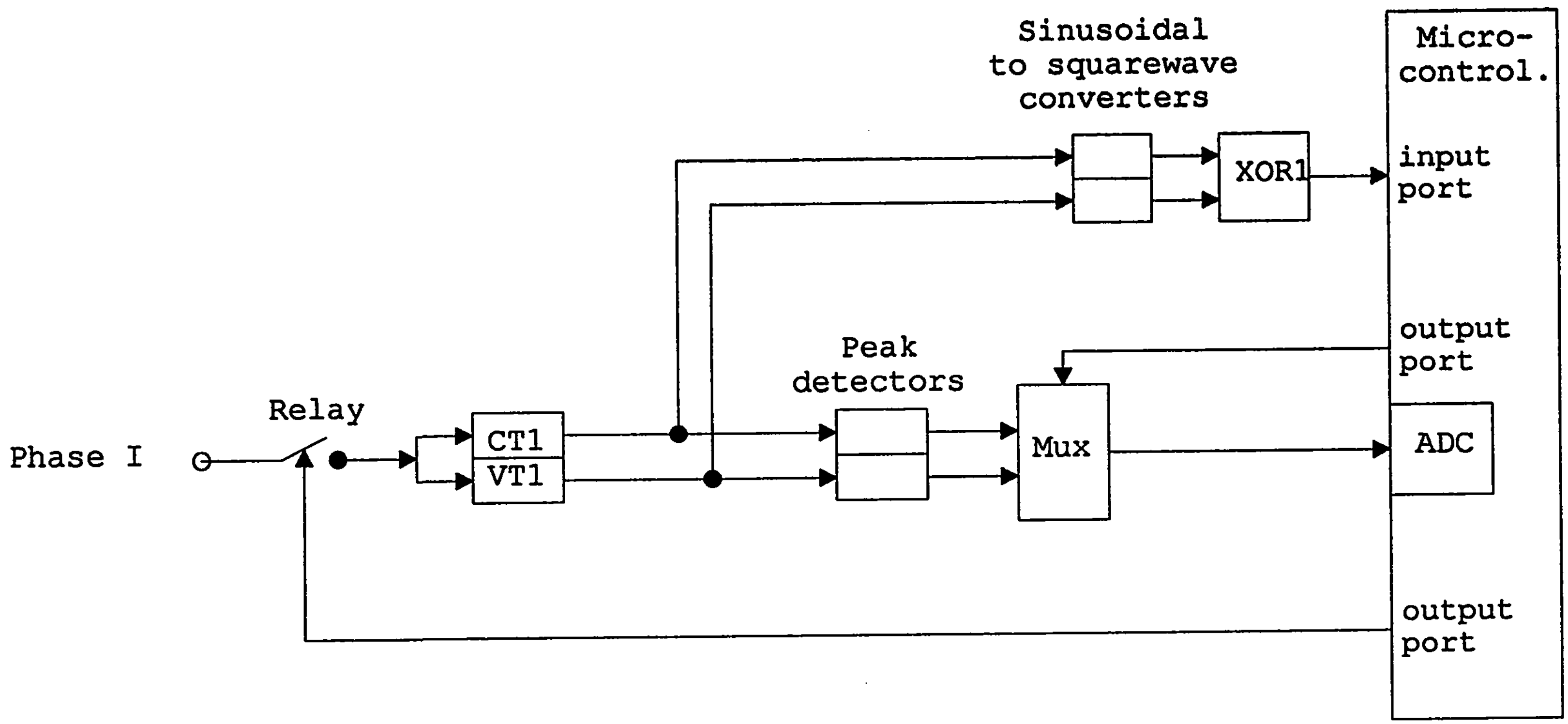

FIGURE 4.1,ZERO-CROSSING WATTMETER
FOR SINGLE-PHASE

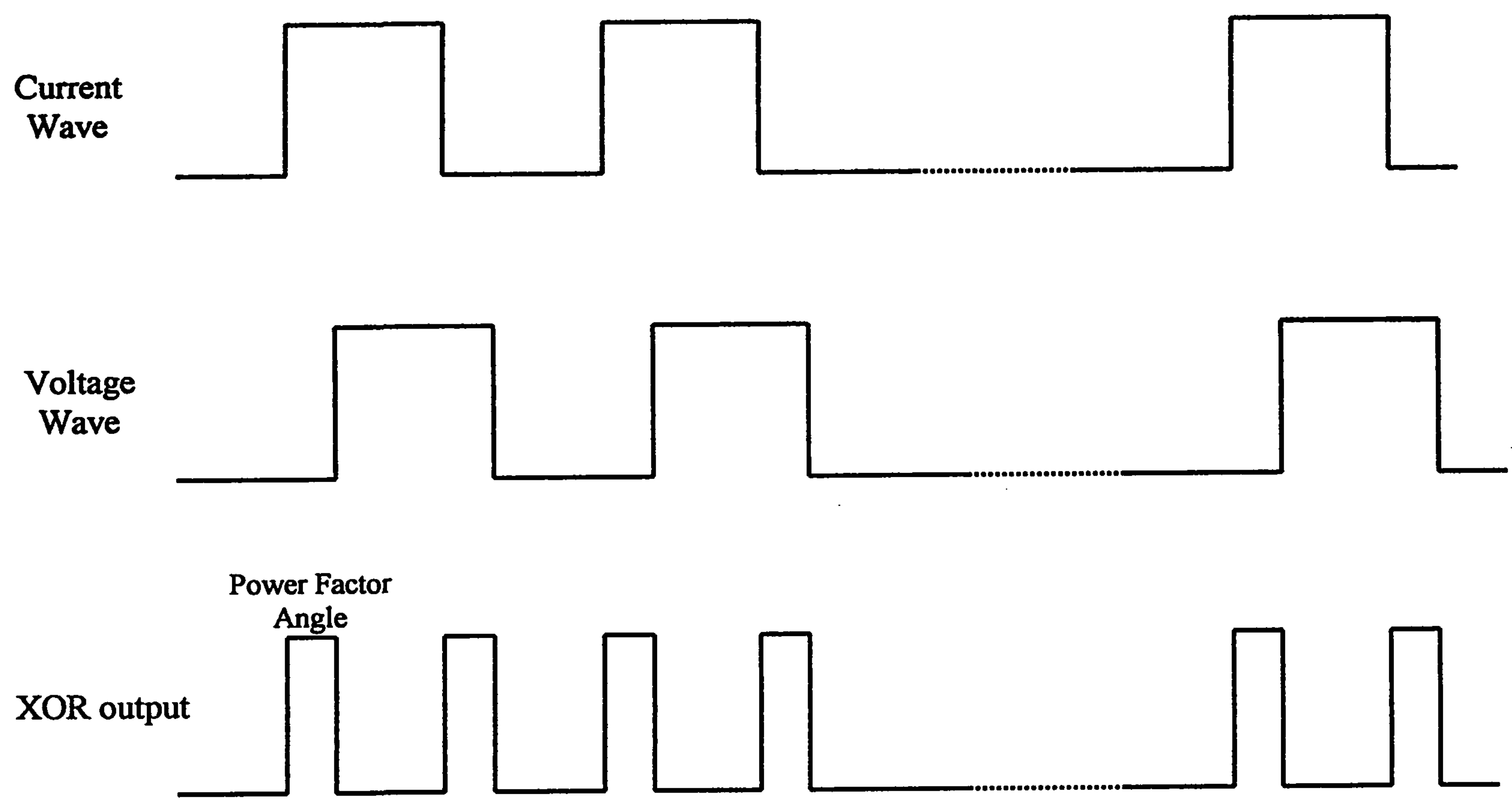

FIGURE 4.2, POWER FACTOR ANGLE MEASUREMENT

$$\tau = \frac{1}{2 \times f} \equiv 180^{\circ}$$

where

f = Source frequency

$$\text{Power factor angle } (\theta_{measured}) = \frac{T_{XOR} \times 180^{\circ}}{\tau} \qquad (4.1)$$

Then, the instantaneous real power is given by

$$P = \frac{1}{2} V_{measured} I_{measured} \cos(\theta_{measured}) \qquad (4.2)$$

The energy due to the real power for ($k \cdot mT$, k is an integer number) is given by

$$W_P = \frac{mT}{2} \sum_{i=1}^{k} V_i I_i \cos(\theta_i) \qquad (4.3)$$

Each sample is taken within mT *Sec.*. A timer is used to trigger the sampling every mT *Sec.*.

For three-phase feeder, the energy due to the real power is given by

$$W_{3P} = \frac{mT}{2} \left\{ \sum_{i=1}^{k} [V_{1i} I_{1i} \cos(\theta_{1i}) + V_{2i} I_{2i} \cos(\theta_{2i}) + V_{3i} I_{3i} \cos(\theta_{3i})] \right\} \qquad (4.4)$$

Each sample of the three-phase is taken within *mT Sec.* A timer is used to trigger the sampling every *mT Sec.*.

The block diagram wattmeter configuration for three phase electric feeder is shown in Figure 4.3.

The electricity source feeders are connected to the customer appliances through a heavy duty relays, which are controlled by the microcontroller. These relays are used to automatically disconnect or connect the service. Service disconnection is done, if the customer has a bad credit or the load current exceeds the limit.

The complete three-phase zero-crossing wattmeter circuit configuration is shown in Figure 4.4.

4.2.2 DIGITAL SAMPLING WATTMETER CIRCUIT

The digital sampling wattmeter is very attractive when harmonics present in the load current and voltage source. The basic configuration of the digital sampling wattmeter for one phase feeder is shown in Figure 4.5. The signal conditioning is the same as the zero-crossing technique. The output of the CT is converted to voltage by passing it through a low value resistor. The current and voltage waveforms are fed to sample and hold (S/H) circuits, which are triggered by the microcontroller at the sampling

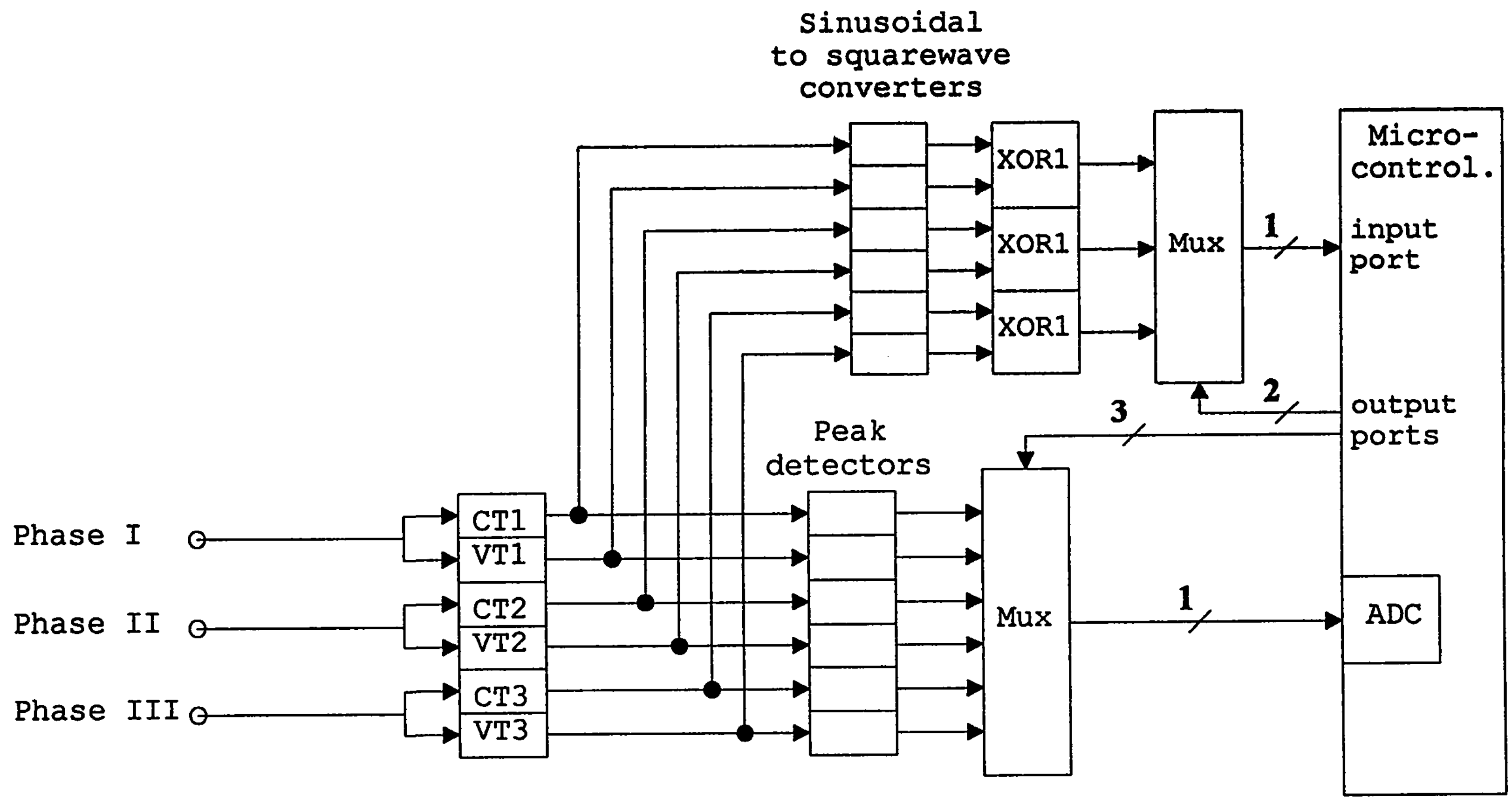

FIGURE 4.3, ZERO-CROSSING WATTMETER FOR THREE PHASES

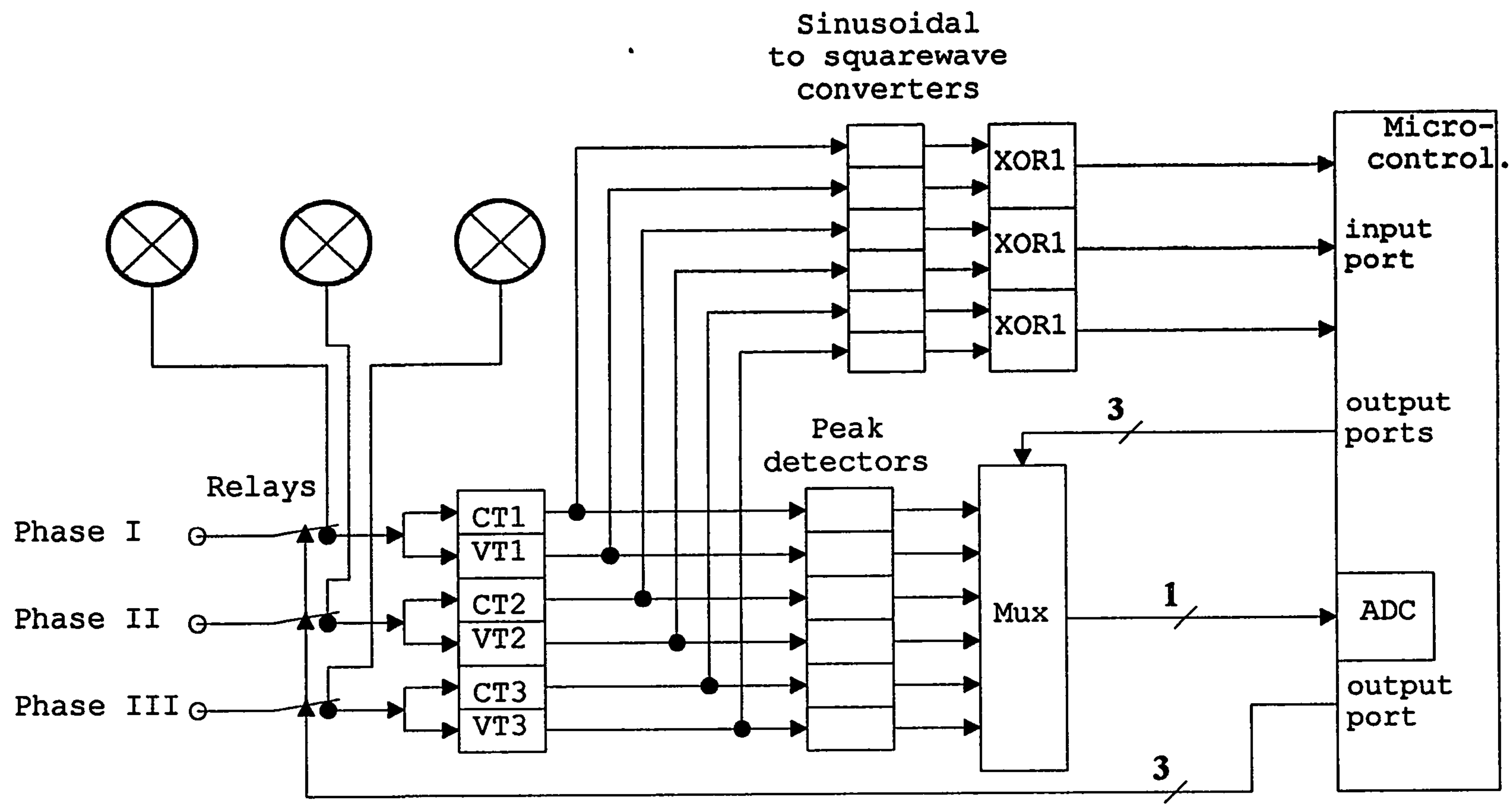

FIGURE 4.4, COMPLETE ZERO-CROSSING WATTMETER
FOR THREE PHASES

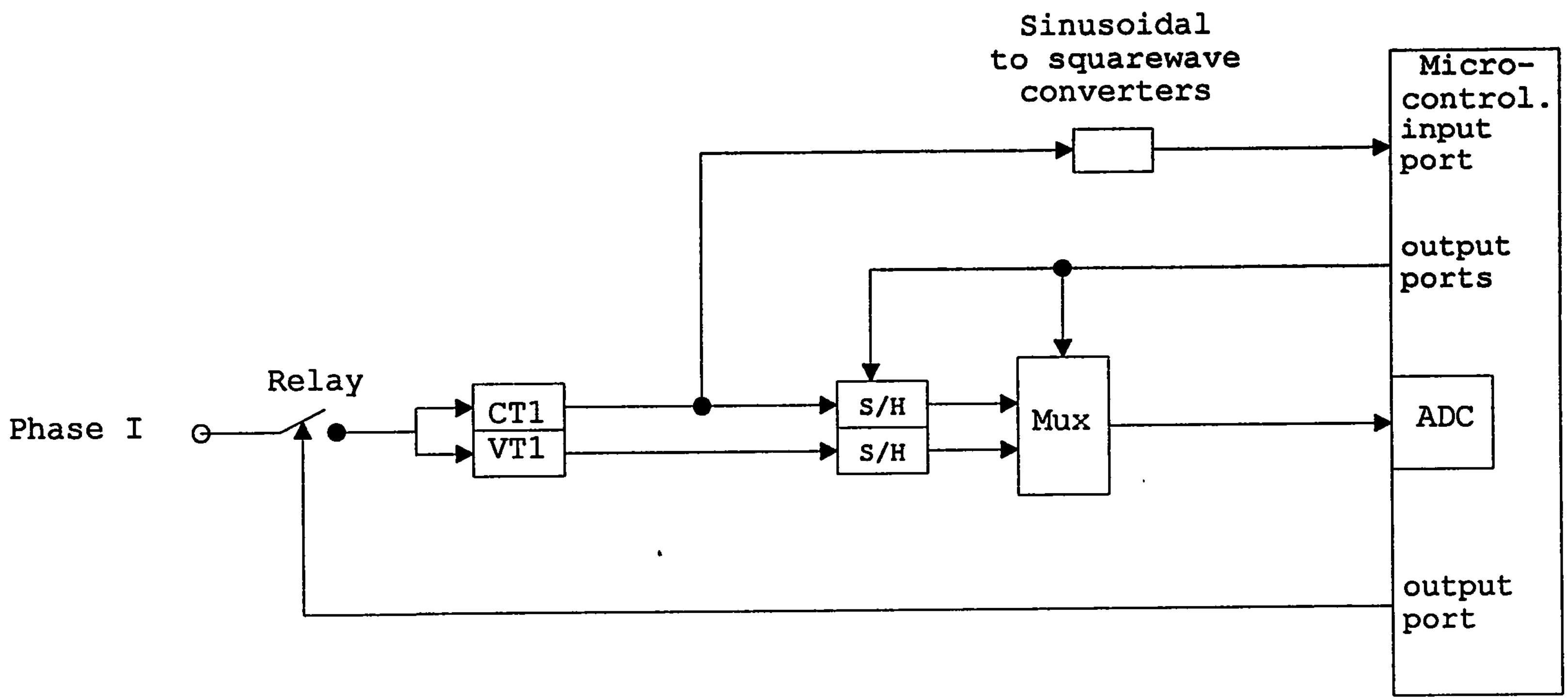

FIGURE 4.5, DIGITAL SAMPLING WATTMETER FOR ONE PHASE

rate. It was seen in Section 3.1 that the recommended number of samples $N=29$. Then, the sampling rate is given by

$$\Delta T=\frac{mT}{29} \tag{4.5}$$

A timer is used to trigger the sampling every $\frac{mT}{29}$ *Sec.*

Therefore, the energy due to the real power for $(k\cdot mT)$ is given by

$$W_P=\sum_{j=1}^{k}\Delta T\sum_{i=1}^{N}v_{ji}i_{ji}=\Delta T\sum_{j=1}^{k}\sum_{i=1}^{N}v_{ji}i_{ji} \tag{4.6}$$

Then, the energy for three-phase feeder is given by

$$W_{3P}=\Delta T\sum_{j=1}^{k}\sum_{i=1}^{N}[v_{1ji}i_{1ji}+v_{2ji}i_{2ji}+v_{3ji}i_{3ji}] \tag{4.7}$$

A timer is used to trigger the sampling every $\frac{mT}{29}$ *Sec.* The required time for scanning the three ADC should be less than ΔT.

The block diagram of the wattmeter configuration for three phase electric feeder is shown in Figure 4.6.

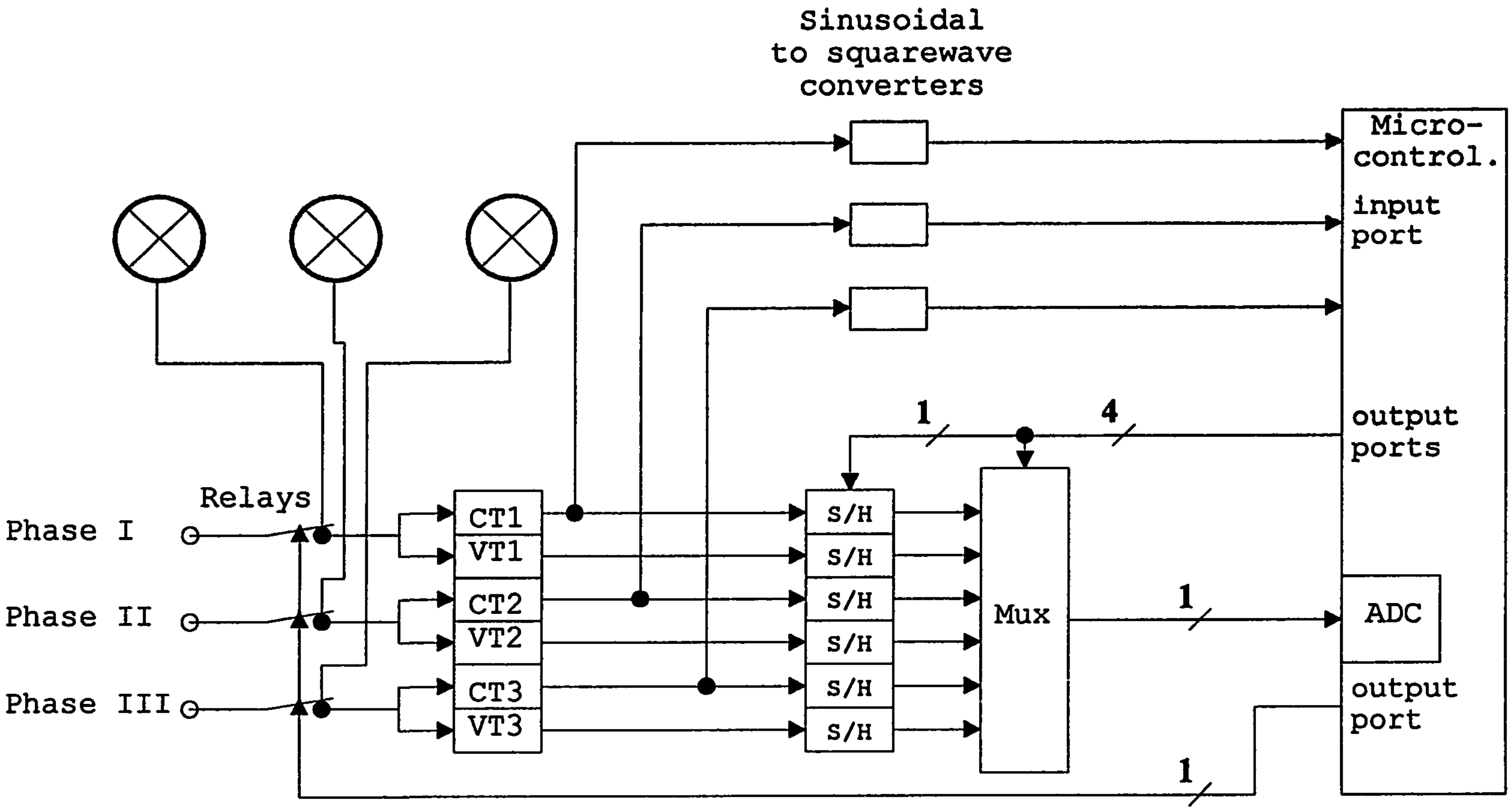

FIGURE 4.6, DIGITAL SAMPLING WATTMETER FOR THREE PHASES

4.3 WATER/GAS METER CIRCUIT DESIGN

An electronic, magnetic, turbine flow meter is used to measure the flow rate Q ($lit./\mathrm{min}$). The magnetic turbine flow meter is recommended to achieve the required accuracy for water/gas flow metering (± 0.5). The proposed circuit configuration is shown in Figure 4.7. The water/gas flow rate is converted to frequency by the turbine flow meter. A frequency to voltage converter is used to convert the frequency to dc voltage. Then, the output dc voltage is read using A/D converter. The volume flow rate is given by

$$f_{meter} = \alpha V_{f/V,measured} \tag{4.8}$$

$$Q_{measured} = \beta f_{meter} \tag{4.9}$$

for t_0 to t_1

$$\text{Water/gas consumption} = \Delta T \sum_{i=1}^{N} Q_{i,measued} \tag{4.10}$$

where

α= Linearity slope for the frequency to voltage converter

β= Linearity slope for the flowmeter

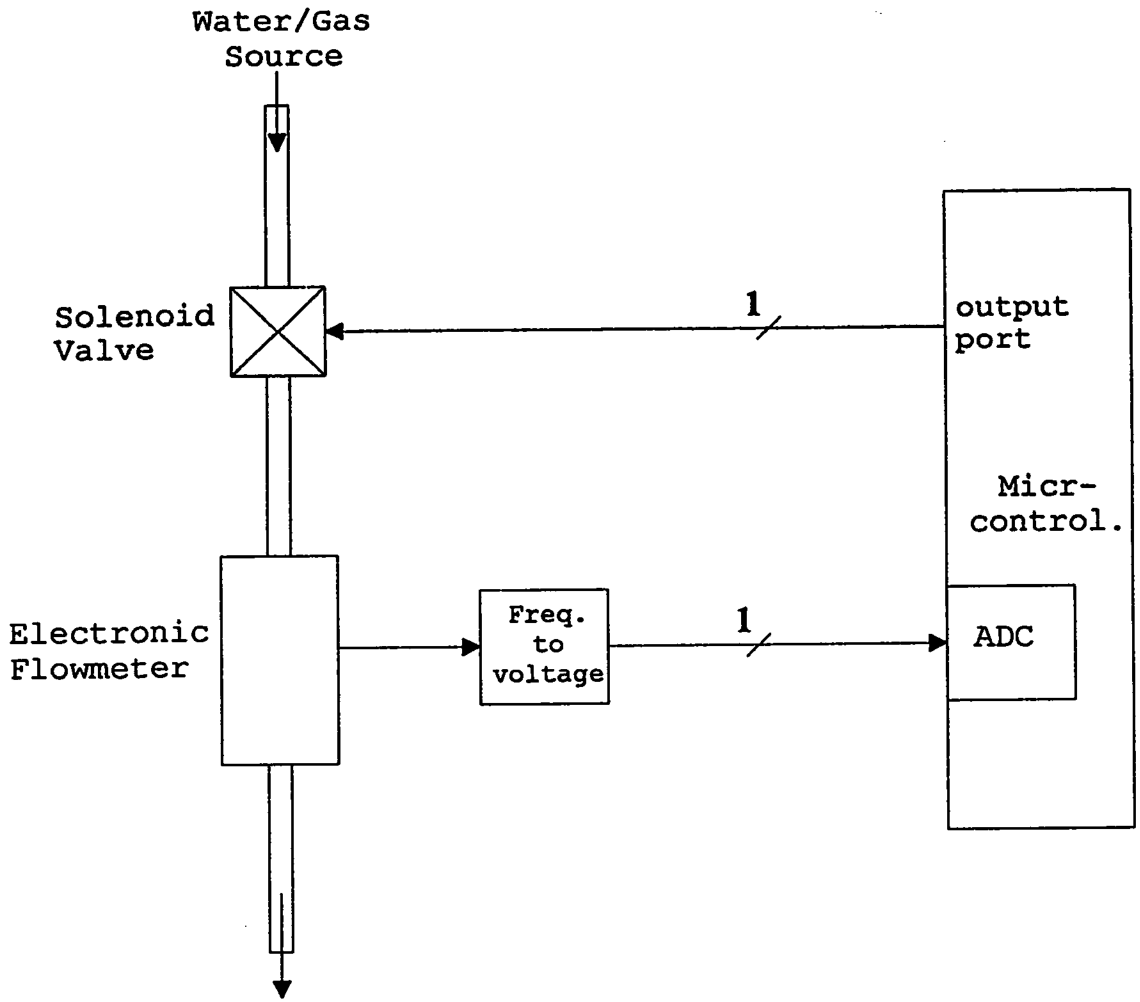

FIGURE 4.7, WATER/GAS METER & CONTROL CIRCUIT CONFIGURATION

A solenoid valve is used to automatically disconnect or connect the water/gas service. This valve is controlled by the microcontroller to disconnect the service, if the customer has a bad credit.

4.4 TELEPHONE CALLS METER CIRCUIT DESIGN

The designed circuit is based on receiving the coin control pulse as an acknowledgment from the central office. The coin control pulse generator consists of a normal battery feed circuit and a reverse battery feed circuit. Either of these circuits is activated according to the battery polarity required. In normal polarity, the normal current I_N is active. In reverse polarity, the reverse current I_R is active. Thus, the subscriber line current I_L is given as $I_L = I_N - I_R$. The reverse current is twice as the normal current and the pulse time is equal to 0.8 *Sec.* [29]. The circuit configuration is shown in Figure 4.8. The telephone line is controlled by the microcontroller via a relay. The line is connected to the user phone set through a polarity protection rectifier bridge. Also, the line is connected to an off/on-hook detector from which it is connected to an interrupt request to indicate the user phone status. The coin pulse from the CO (Central Office) is detected by using a pulse detector circuit, which consists

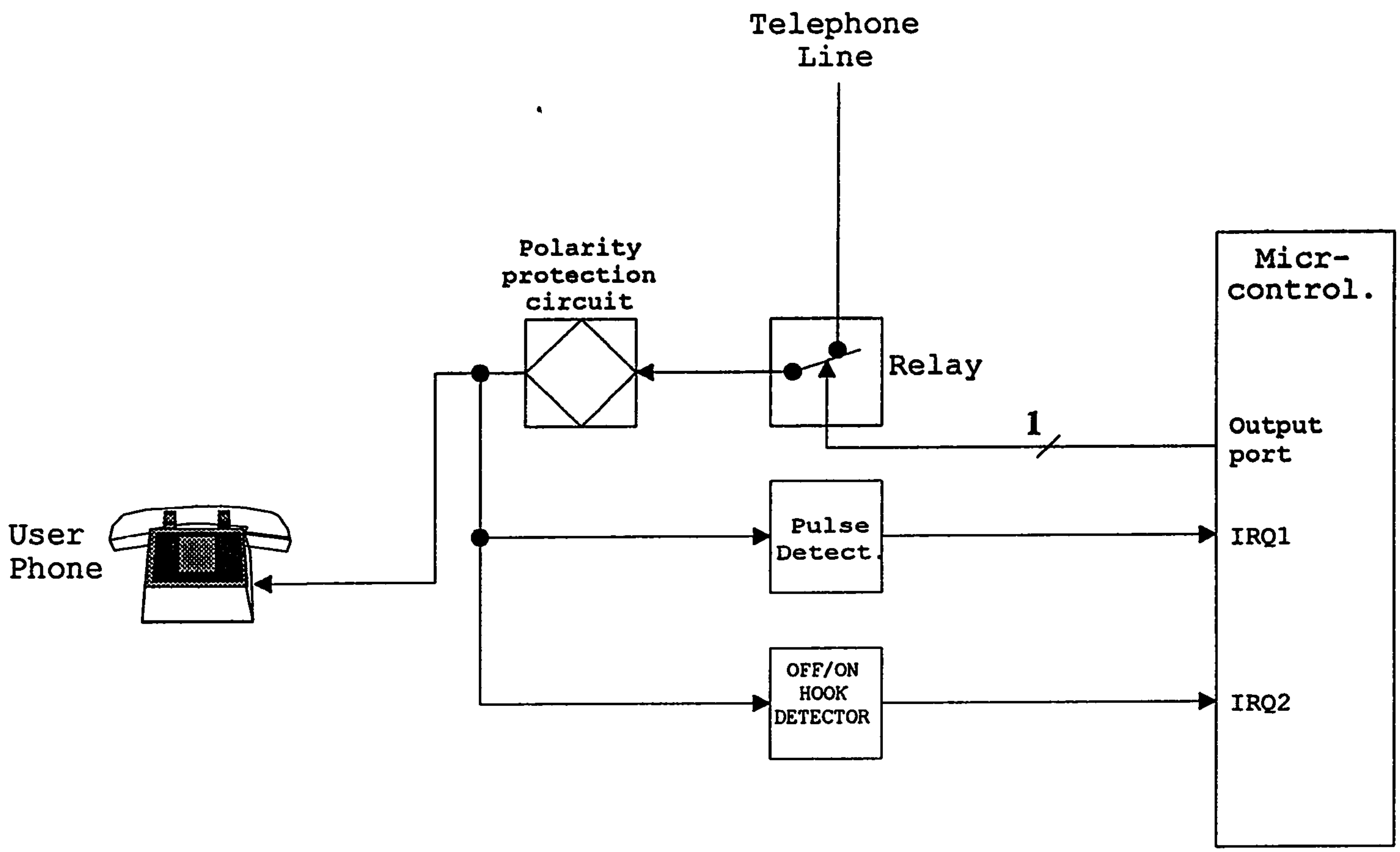

FIGURE 4.8, TELEPHONE CALLS METER & CONTROL CIRCUIT CONFIGURATION

of an optoisolator circuit (discussed in Chapter 5). The detector output is connected to an interrupt which is used to sense the the pulses.

4.5 MAGNETIC CARD MEMORY FORMAT

The proposed memory format for the magnetic card is shown in Figure 4.9a. The magnetic-stripe is divided into three tracks as follows:

- Track 1: in this track , the service code which can be power, water/gas, and/or telephone is stored.

- Track 2: this track of the magnetic stripe is used to store the rate structure and the rate level. This is useful for energy and water/gas services. The rate may be one of the followings:

  1. fixed charge with flat rate consumption.
  2. different rate level for different consumption.
  3. various demand consideration.

  The rate structure can be changed at the time of any new credit purchase.

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Track 1, Service Code
Track 2, Rate Structure
Track 3, Service purchase amount

FIGURE 4.9a
MAGNETIC-STRIP FORMAT

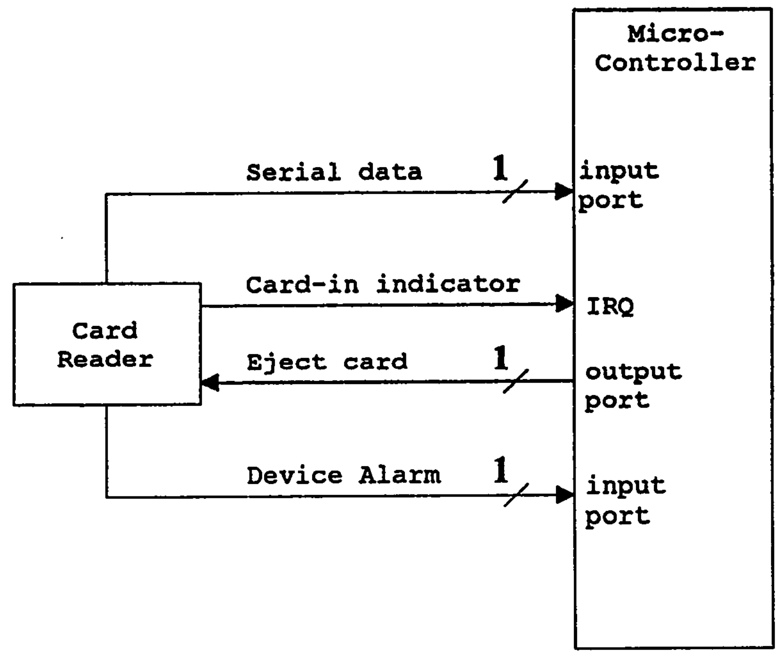


FIGURE 4.9b
CARD READER CONFIGURATION CIRCUIT

- Track 3: the new credit of purchase is stored in this track.

A card reader is used to read the magnetic card and passes the code information to the microcontroller. The card reader is designed to be able to decode the encoded data on the magnetic-stripe. A card is detected via interrupt pin connection. After the card is read, the rate value and the credit amount are stored in the microcontroller EEPROM. The card reader system configuration is shown in Figure 4.9b.

4.6 SYSTEM INTEGRATION

The three meter circuits and the card reader circuit are integrated in one single board as shown in Figure 4.10. The digital sampling wattmeter, the water/gas flow meter, the telephone calls meter, and the card reader are integrated with a high speed microcontroller. The recommended microcontroller is either Intel 8096 or Motorola 68HC16, which are 16-bit processors (See Appendix F). The serial port is used to access the system for maintenance and trouble shooting. It is also used for software parameters update in EEPROM. A battery backup is used to operate the system in case of electrical power failure. An alphanumerically display is used to display

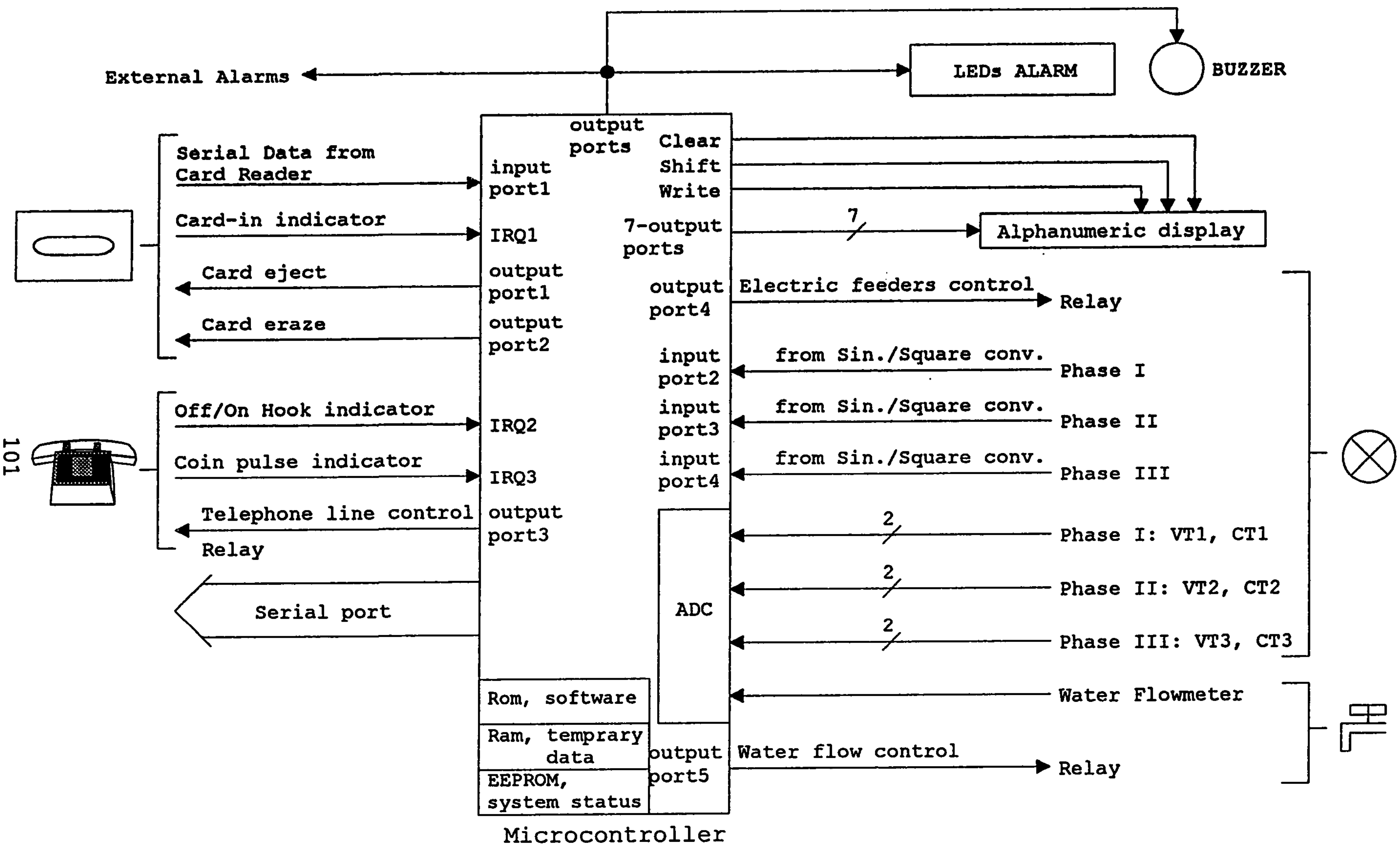


FIGURE 4.10, COMPLETE SYSTEM CONFIGURATION

the services consumption costs, the available credit, and the services consumption. Various alarms are used to indicate any system malfunction, such as low credit, service disconnection, overload current, microcontroller failure, and card reader failure. Alarms are also available externally to extend the alarms to the desired location.

4.7 SOFTWARE ALGORITHMS

The software algorithms are based on some assumptions which are presented in this section. Also, the algorithms flow charts are discussed.

4.7.1 ASSUMPTIONS

The following are assumed in developing the algorithms:

1. Sampling rate: The sampling period for the energy metering is determined during the measurement process and the sampling period for the water/gas metering is assumed to be >1.0 *Sec*.

2. Circuits priority: All meters are served through an interrupt request. The water/gas circuit interrupt is designed so that no conflict occur with the energy meter interrupt. If the telephone circuit interrupt occurs while the microcontroller serving the water/gas or power

interrupt, the telephone interrupt will be delayed until the current interrupt is served.

3. Service rate: The service rate for energy and water/gas systems is fixed; however, different rate structures are considered in the design.

4. Current overload: An energy overload is considered when a load current exceeds the rated by 10%.

5. Grace period: After a prepaid money is spent (consumed), a period of time is specified, by the utility company, after which the service is automatically disconnected.

6. Minimum credit alarm: A buzzer alarm will sound to alert the consumer to get new credit.

7. Display update: This is the time for one display screen; it is assumed to be 5.0 *Sec.*

8. System startup conditions: When the system is just startup, all services will be connected to the customer.

4.7.2 SOFTWARE FLOWCHARTS

Figures 4.11a, b, c, d & e show the general flowcharts for the proposed system metering procedure. The microcontroller starts by loading the initial startup values, such as rates, maximum load current, customer credit and system status (services consumption costs) from the internal EEPROM. Also, the water/gas timer is initialized with a sampling period for triggering the routine to calculate water/gas consumption and costs. Then, alarms will be generated for overdue, overload or any system failure. If the customer has previously bad credit and the grace period has passed for one or more services, the service will be automatically disconnected. The power timer that is used to trigger the energy routine for calculating the energy consumption and costs is loaded with the sampling period. The power sampling period is measured from the maximum current frequency of the three phases. On water/gas timer interrupt, the water/gas flow is measured, the costs are calculated, and the result values are displayed on the alphanumeric screen. On power timer interrupt, the electric energy is measured and calculated, the costs are calculated, the maximum current frequency is measured and loaded to the power timer interrupt, and the results values are displayed on the alphanumeric display. On the coin pulse interrupt, the available credit is deducted by one unit. On card-in

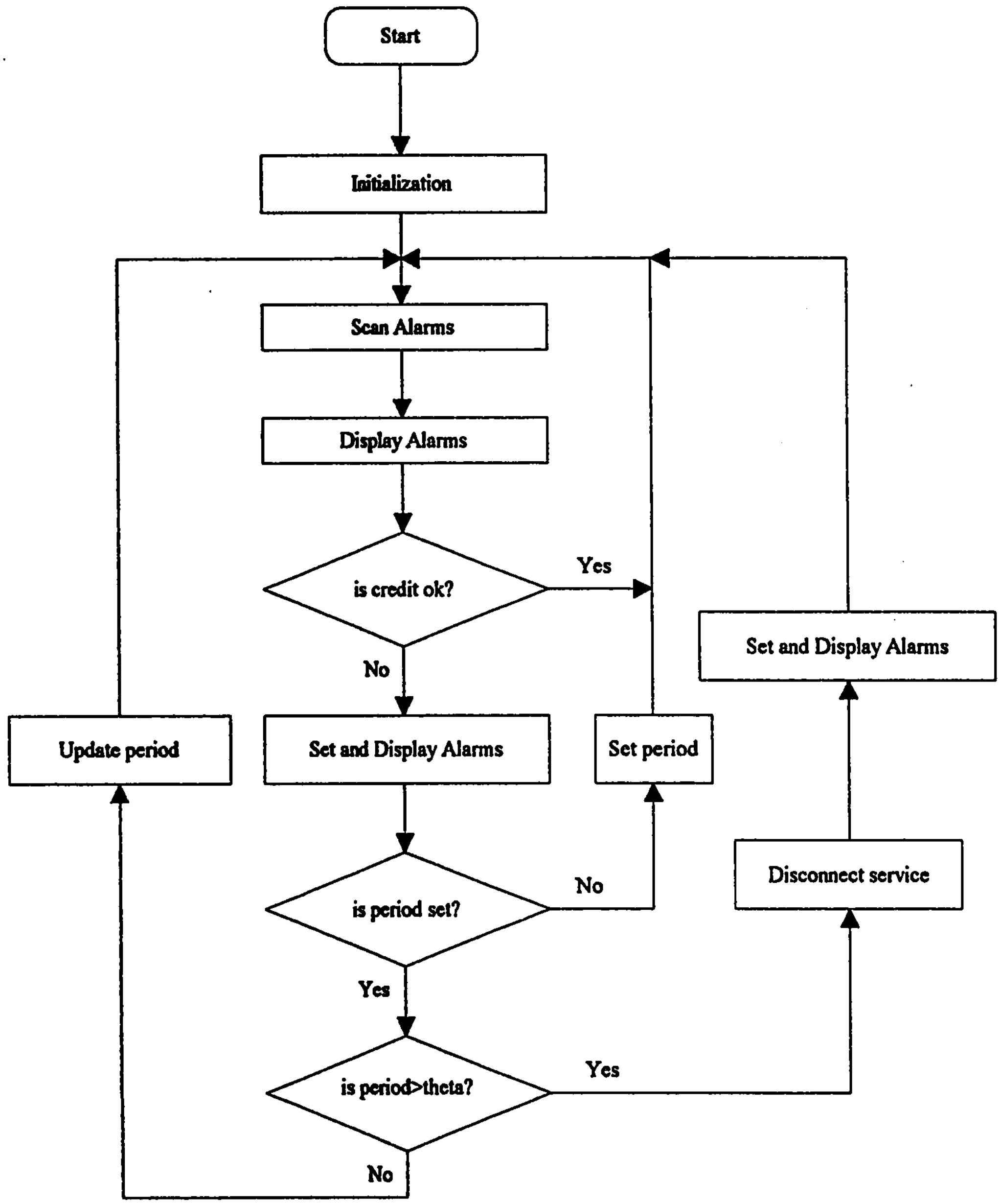

Start
Initialization
Scan Alarms
Display Alarms
is credit ok?
Yes
No
Set and Display Alarms
Update period
Set and Display Alarms
Set period
is period set?
No
Disconnect service
Yes
is period>theta?
Yes
No

FIGURE 4.11a

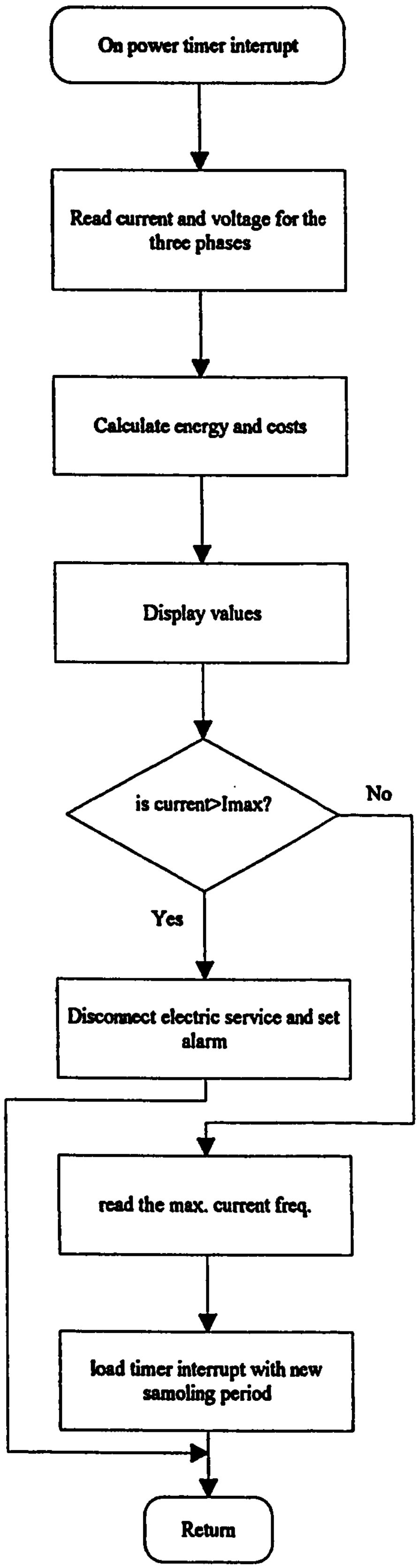


FIGURE 4.11b

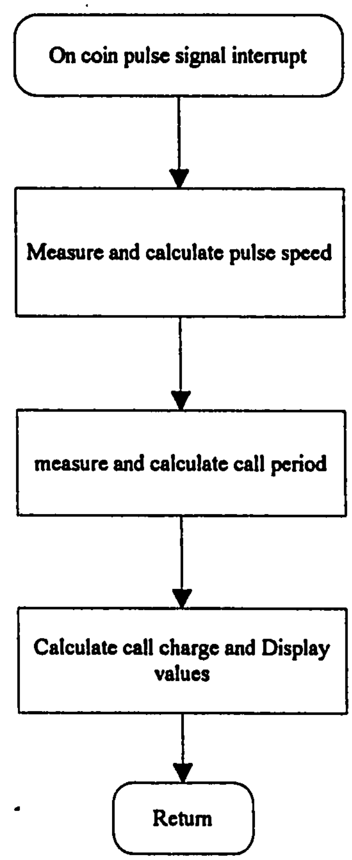


FIGURE 4.11c

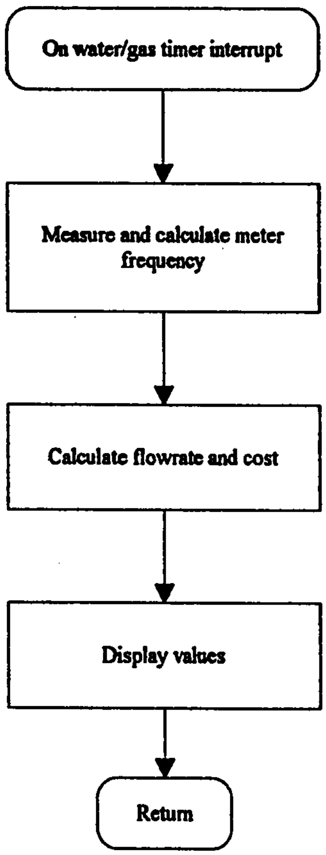


FIGURE 4.11d

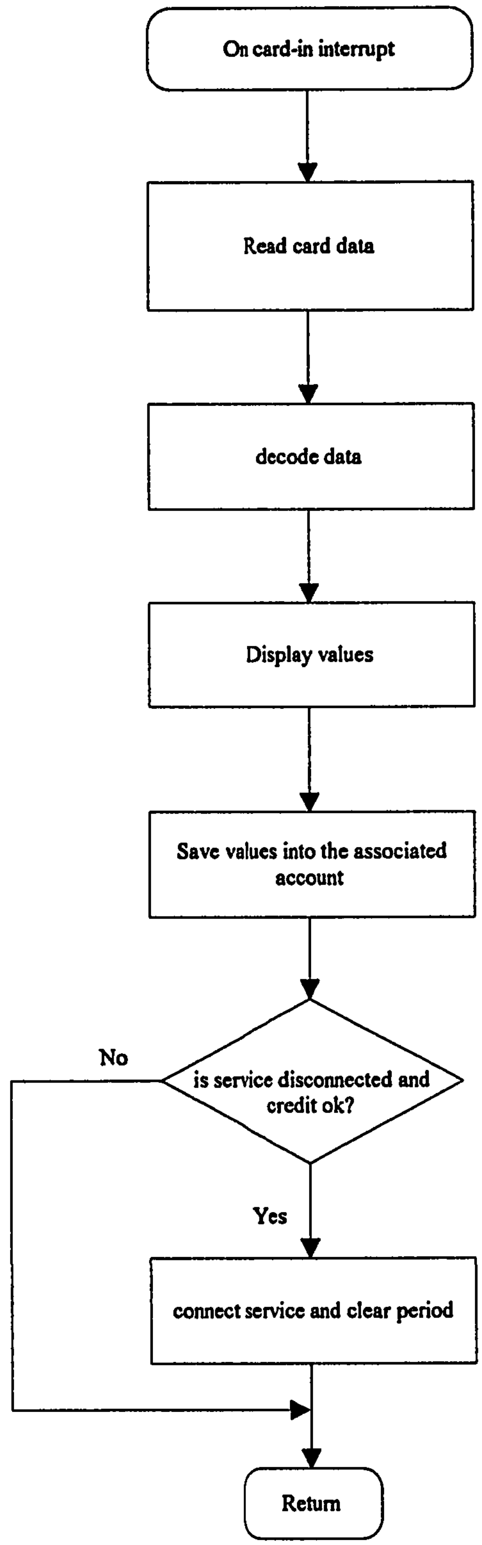


FIGURE 4.11e

interrupt, the card is read and decoded, and the credit and the rate are loaded to the associated service code and displayed on the alphanumeric screen. The data on the magnetic-stripe is erased and the card is ejected. Then, the program loops back by checking the system alarms and servicing the various interrupts.

The following conditions are assumed in the program:

1. The digital sampling wattmeter for three phases is used in this program.

2. Theta that is used in the program is the threshold Grace period.

3. The credit value is the available credit for each service and is checked for availability for each service separately.

4. Imax threshold is defined in Section 4.6.1, item 4.

SUMMARY

In this chapter, the proposed system configuration including wattmeter, flow meter, telephone calls meter, card reader and alarms circuits are designed using "off the shelf" components. A new magnetic-stripe data format is introduced.

In the next chapter, the overall system performance is evaluated by designing and implementing a prototype system based on a personal computer.

CHAPTER 5

PROPOSED SYSTEM IMPLEMENTATION AND EVALUATION

In this chapter, a prototype of the automated billing system is designed and built utilizing a personal computer. The realization of the proposed system is achieved by hardware implementation and software development. Figure 5.1 shows the system hardware architecture. The system software consists of two main programs. The first program is written for system maintenance, to test and evaluate each utility meter separately. The second one is an integrated software package which is developed to operate and command the overall system. Furthermore, the effects of circuits interference is discussed.

5.1 PROTOTYPE SYSTEM OBJECTIVES

The objectives of the prototype can be summarized as follows:

1. Build each meter hardware circuit as stand alone module.

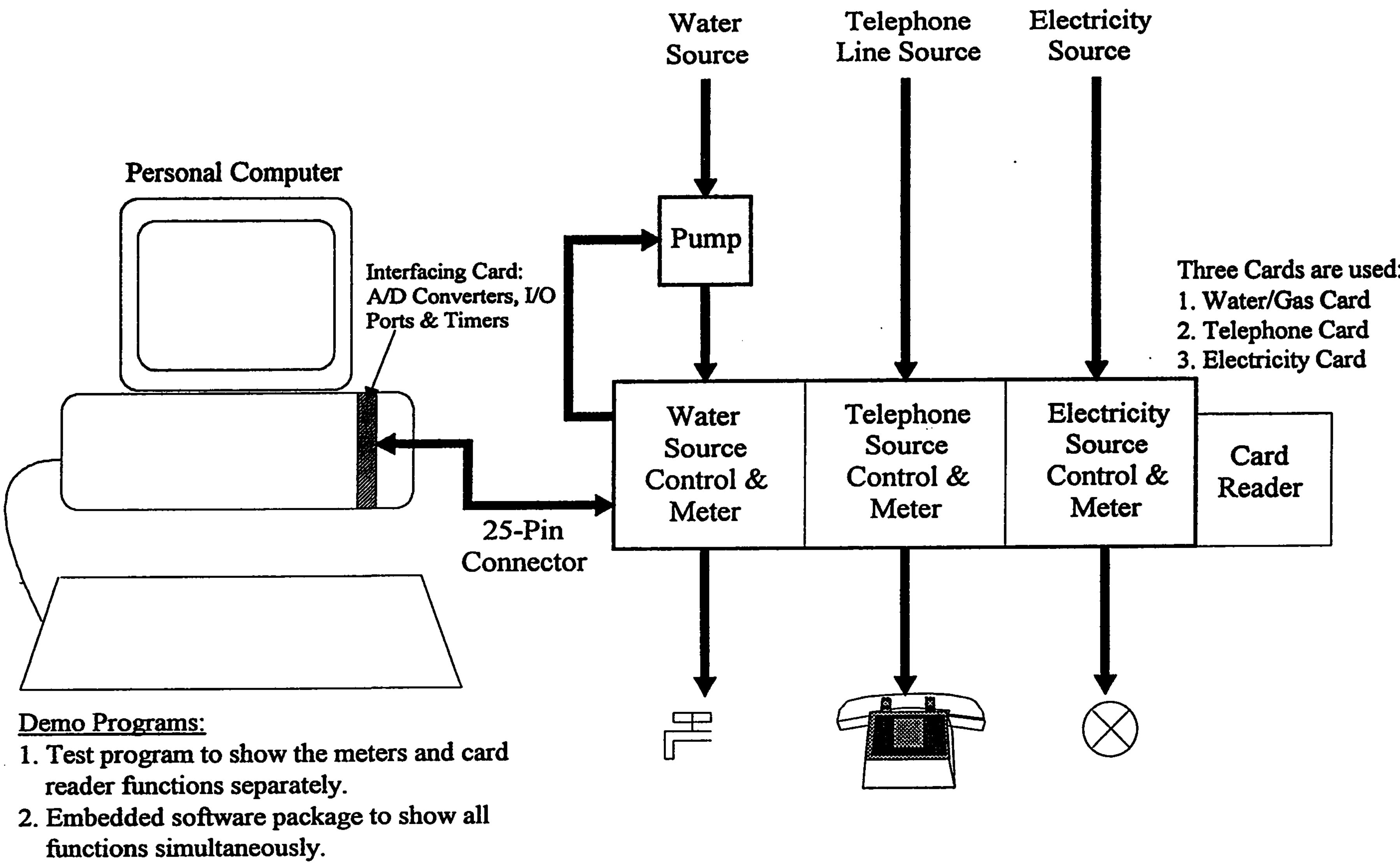


Figure 5.1
Automated Billing System for Public Utilities (ABS)
Prototype System

2. Test the accuracy of the energy metering software algorithm.

3. Test the accuracy of the energy signal conditioning circuit.

4. Find the optimum sampling rate for energy measurement.

5. Test the accuracy of the water/gas metering software algorithm. The algorithm will show destination, start time, stop time, and call charge, which are validated by calculation.

6. Test the accuracy of the water/gas signal conditioning circuit.

7. Find the optimum sampling rate for water/gas measurement.

8. Test the accuracy of the telephone calls metering software algorithm.

9. Test the accuracy of the telephone line interfacing circuit.

In general, the main objective of the prototype is to build and test each individual module as stand-alone unit.

Then, each meter is tested under different loads and conditions.

5.2 PROTOTYPE DESIGN PARAMETERS

Various design parameters are considered in the prototype design. Followings are description of the main parameters considered:

1. Single phase electric source is used ($127V_{rms}$).

2. The maximum load current is 10 A_{rms} .

3. The zero-crossing wattmeter is used.

4. Since, the maximum current for the prototype is low, a low series resistor is used instead of CT.

5. Air is used as a fluid source.

6. One fluid (air) source is used.

7. The air flow is controlled by a pump.

8. An optical turbine flow meter is used.

9. One telephone line is used.

10. The telephone call acknowledgment detection is based on the battery interruption or polarity reversal. However, due to the requirement to identify which method is used for supervision, a manual supervision is provided for demonstration.

11. The maximum utility service purchase is 100 unit.

12. The prototype is interfaced to a personal computer as a microcontroller.

5.3 ENERGY METER IMPLEMENTATION

The zero-crossing circuit is shown in Figure 5.2. a voltage transformer of a ratio 1:75 is used with a primary voltage of 127 V_{rms} and a secondary voltage of $1.7V_{rms}$. The current is measured by inserting a very low resistor (.1 ohm, 15W) between the source and the load. This resistor is used to convert the current to voltage. Then, a 1:1 transformer is used to isolate the grounding between analog and digital. The output of the current to voltage converter circuit is fed to an amplifier to amplify the signal by a factor of 10, as shown in Figure 5.3. The voltage and current-voltage outputs are connected to the A/D

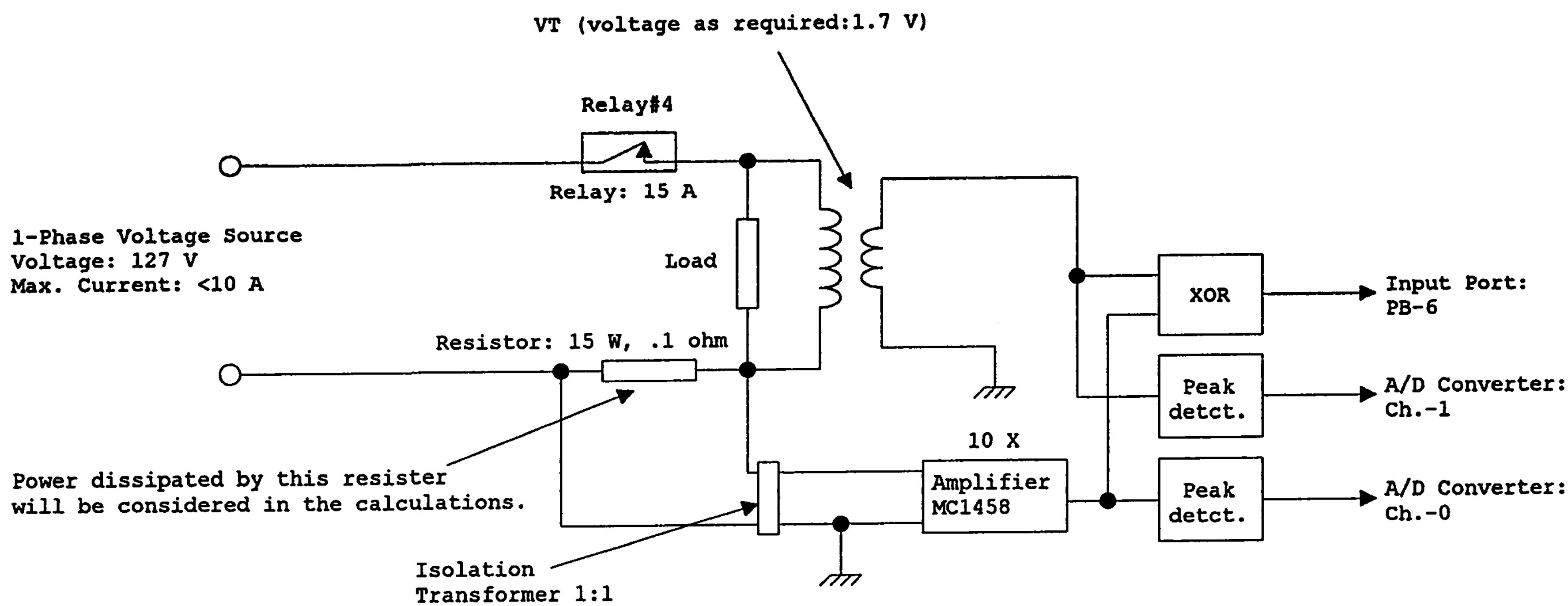
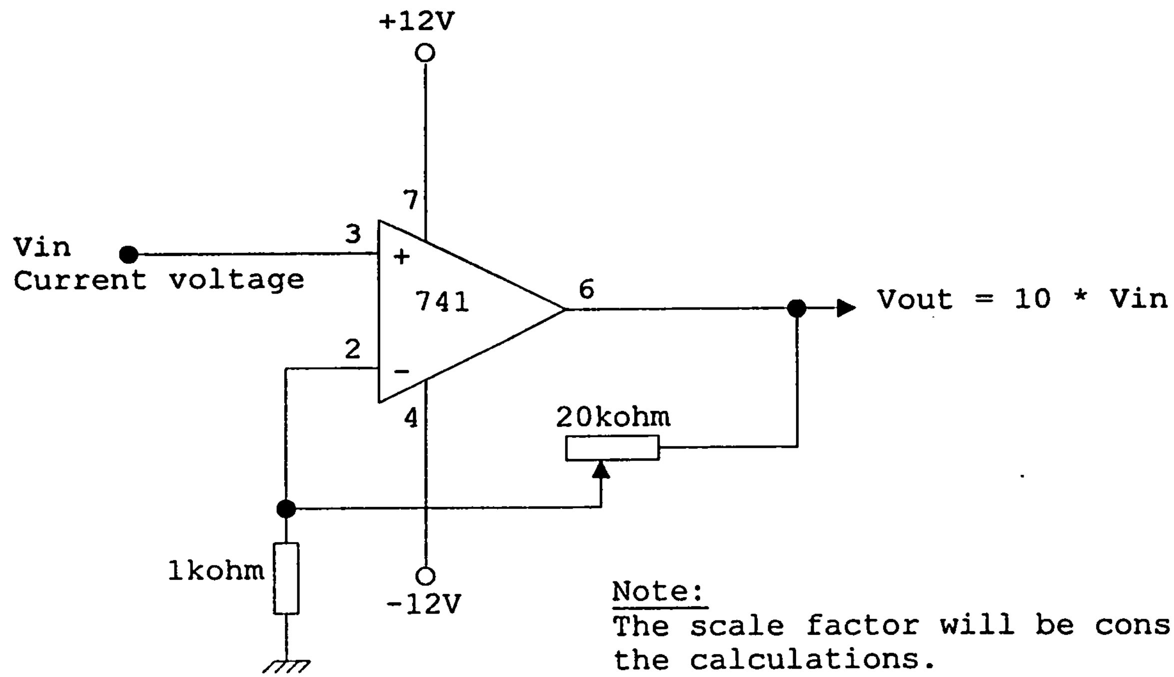


FIGURE 5.2
ZERO-CROSSING WATTMETER CIRCUIT CONFIGURATION



<u>Note:</u>
The scale factor will be considered in the calculations.

FIGURE 5.3, AMPLIFIER CIRCUIT

converters via a peak detector circuit. The peak detector circuit is shown in Figure 5.4. The power factor angle is measured using the circuit shown in Figure 5.5. The voltage and current signals are connected to comparators to convert the sinusoidal signals to square signals. Then, the square signals are fed to an exclusive OR, that output represents the phase difference between the two signals, which gives the power factor angle as a pulse.

The voltage transformer has a ratio of 1:75. The primary voltage is 127 Vrms and the secondary output is 1.7 Vrms at max.

$$V_{secondary} = \frac{V_{primary}}{75}$$

The secondarry voltage is converted to digital signal via 12bit-ADC, a bibolar with a peak voltage equal to 10 volts.

$$\text{ADC Resolution for voltage} = \frac{10}{2^{11}} \times \frac{V_{primary}}{V_{secondary}} = 4.88 \times 10^{-3} \times 75 = 0.366V$$

$$\text{ADC Resolution for current} = \frac{10}{2^{11}} = 4.88mA$$

The current transformer has a secondary current of 1 Arms at max..

$I_{load} = 10\,A_{rms}$ (max.)

Series resistor $= 0.1\Omega$

$\Rightarrow$ Voltage across the resistor $V_R = 0.1\Omega \times I_{load}$

The voltage output of the amplifier $V_{out} = 10 \times V_R$

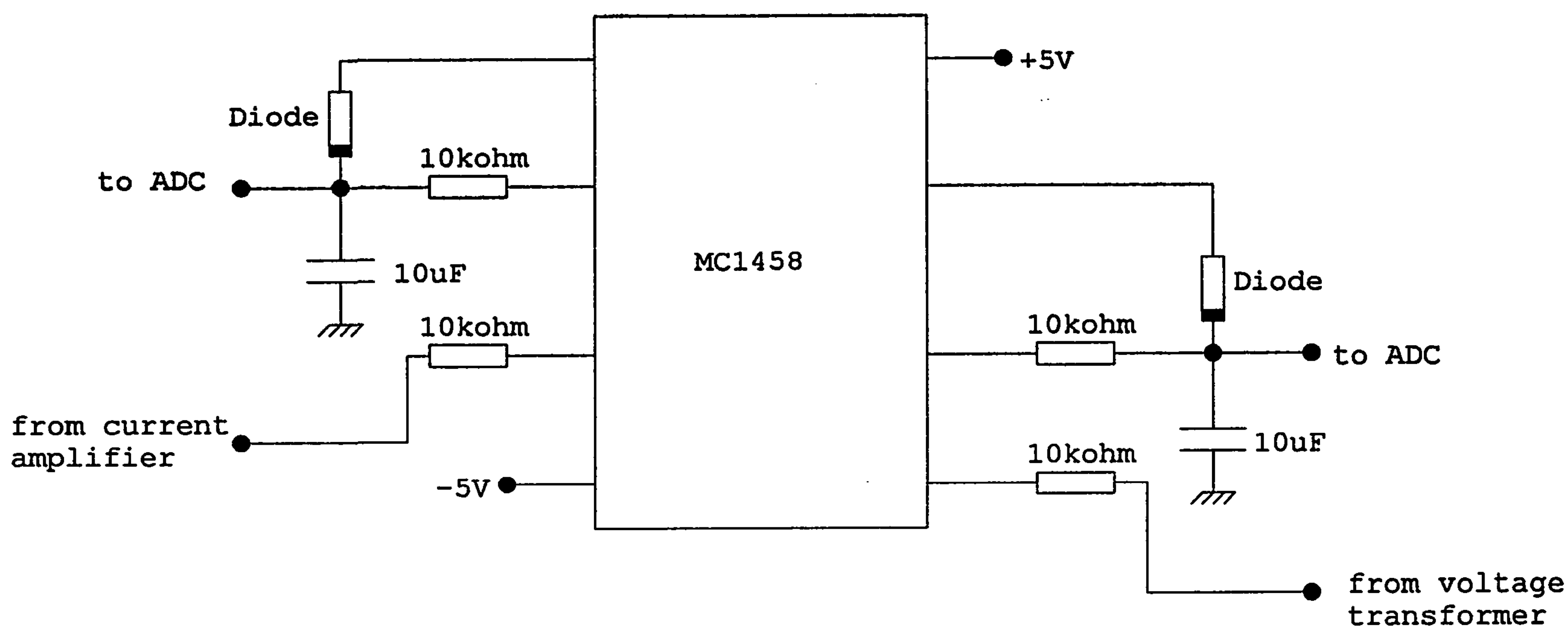


FIGURE 5.4, PEAK DETECTOR CIRCUIT

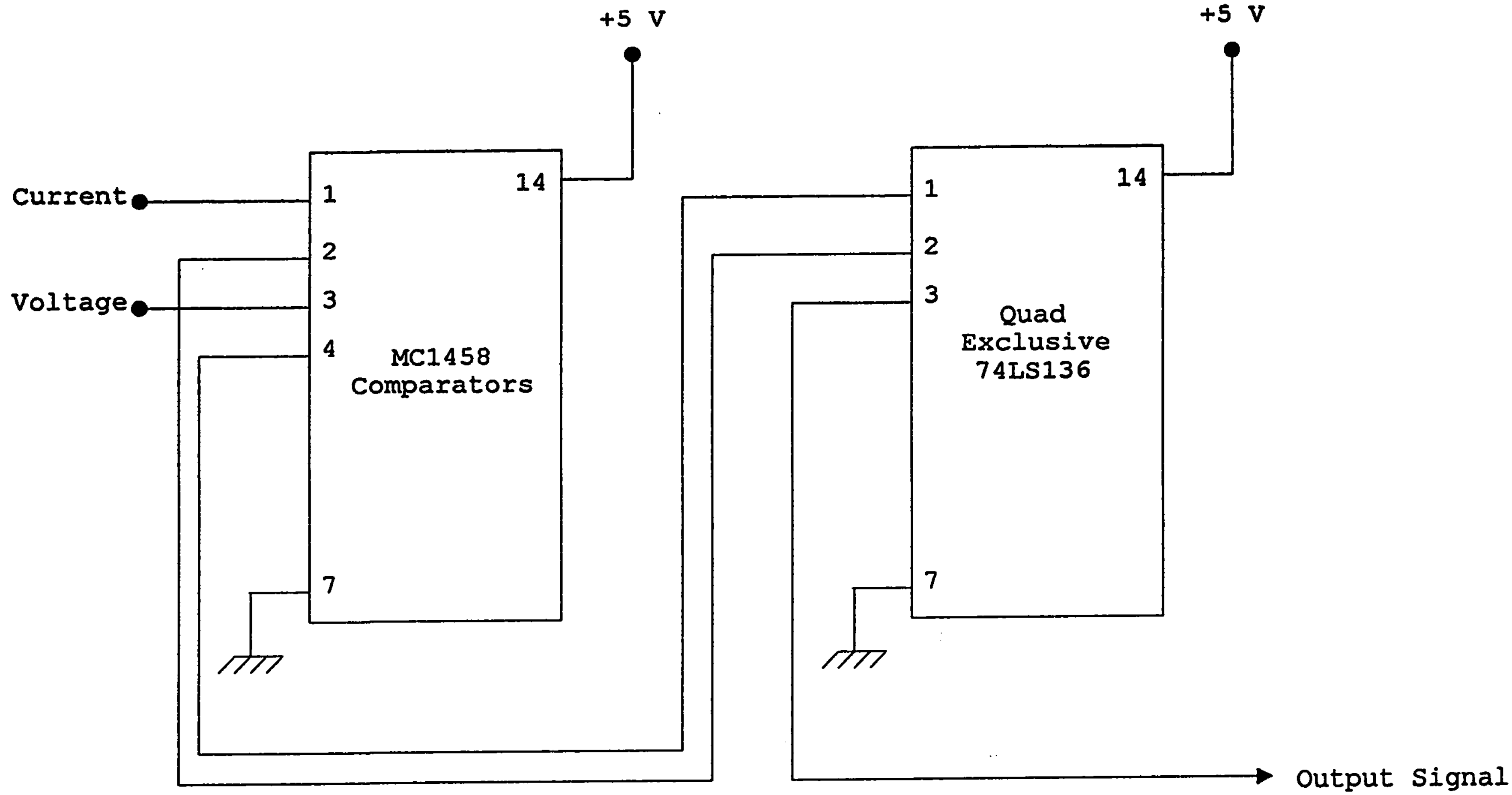


FIGURE 5.5, POWER FACTOR CIRCUIT

The power factor angle between the voltage and current is measured by finding the output pulse width of the XOR Gate. The angle is given by equation (4.1), where $\tau = \frac{1}{2f} = 8.33 \times 10^{-3} Sec$. Then, the instantaneous real power is given by equation (4.2).

The 15 A relay that is shown in Figure 5.2 is used to control the source feeder to connect or disconnect the load in the cases of overdue or overload. This relay is controlled by the computer via the I/O interface.

The calibration of this circuit is done by having a pure resistance load. Comparing the load current, voltage, and power factor angle read by the oscilloscope to the current, voltage, and power factor angle read by the proposed circuit, the prposed circuit can be accordingly tuned to meet the readings by the oscillosope.

5.4 WATER/GAS FLOW METER IMPLEMENTATION

The complete circuit configuration is shown in Figure 5.6. The flow sensor that is used in this project is an optical turbine flow sensor. The turbine flow sensor consists of an infra-red emitting diode, which is directed to the receiver. The receiver has a built-in voltage regulator, photo diode, amplifier, schmitt trigger and

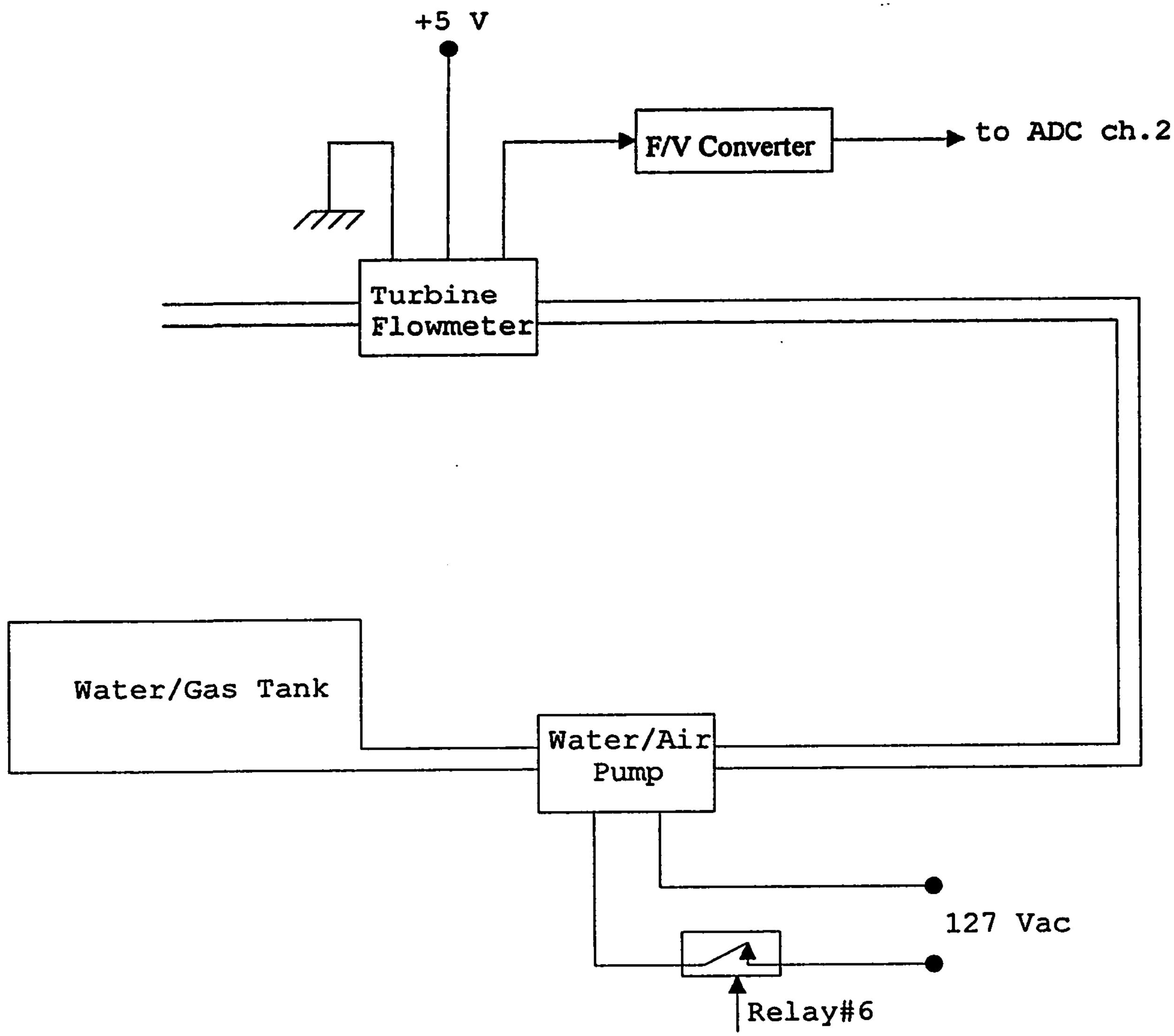


FIGURE 5.6
WATER FLOWMETER PROTOTYPE SYSTEM

output stage. Every turbine blade passage blocks the light beam and reduces the level of the output signal from +Vcc to typically 200mV (maximum 400mV). The output signal is amplified and passed to the schmitt trigger to convert the sinusoidal wave to square wave. The output of the schmitt is connected to an output stage, which is a transistor. The collector pin is connected to Vcc (+5V). The +5V is chosen so that the output of the turbine flow sensor is compatible with TTL circuits. The internal circuitry for the turbine flow sensor is shown in Figure 5.7.

Figure 5.8 shows the relation between flow rate (Litters per minute) and frequency (Pulses per second). The flow sensor has a linear relationship between the flow and the output frequency for the range between 0.25 to 6.5 Litter/min. The linearity error of this sensor is ±1% at FSD (Full Scale Deflection). This flow meter has a slope of +76.92 [37].

Therefore, the flow rate is given by

$$Q = \frac{f_{measured}}{76.92} Litre/\min. \qquad (5.1)$$

The output frequency from the flow meter is converted to dc signals using the circuit shown in Figure 5.9. Then, the output dc voltage is fed to an ADC.

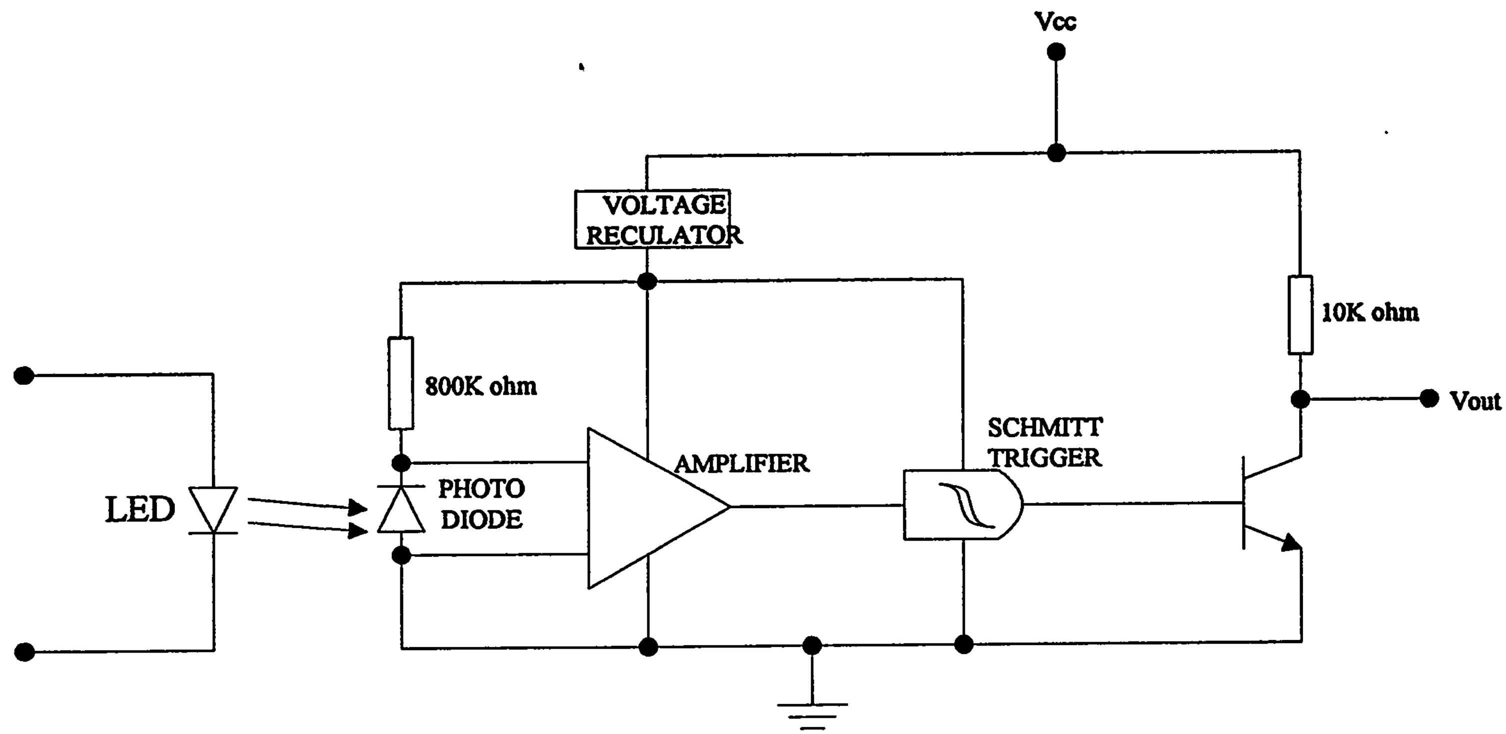


FIGURE 5.7, FLOW SENSOR INTERNAL CIRCUIT

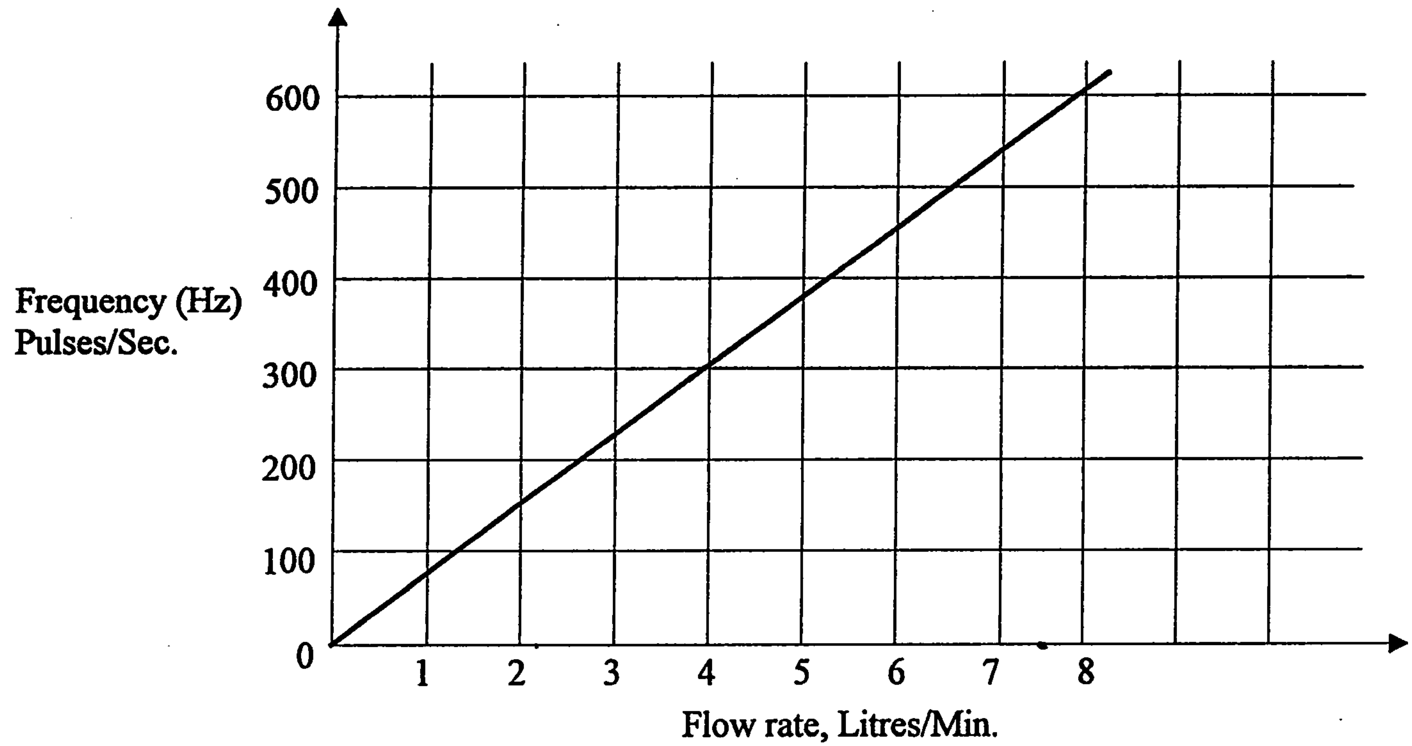


FIGURE 5.8, FLOW RATE AND FREQUENCY RELATION

$V_{out} = 2f_{in}(V_{ref}C_{ref}R_{in})$
$C_{ref} = 39pF$
$V_{ref} = -5\ V$

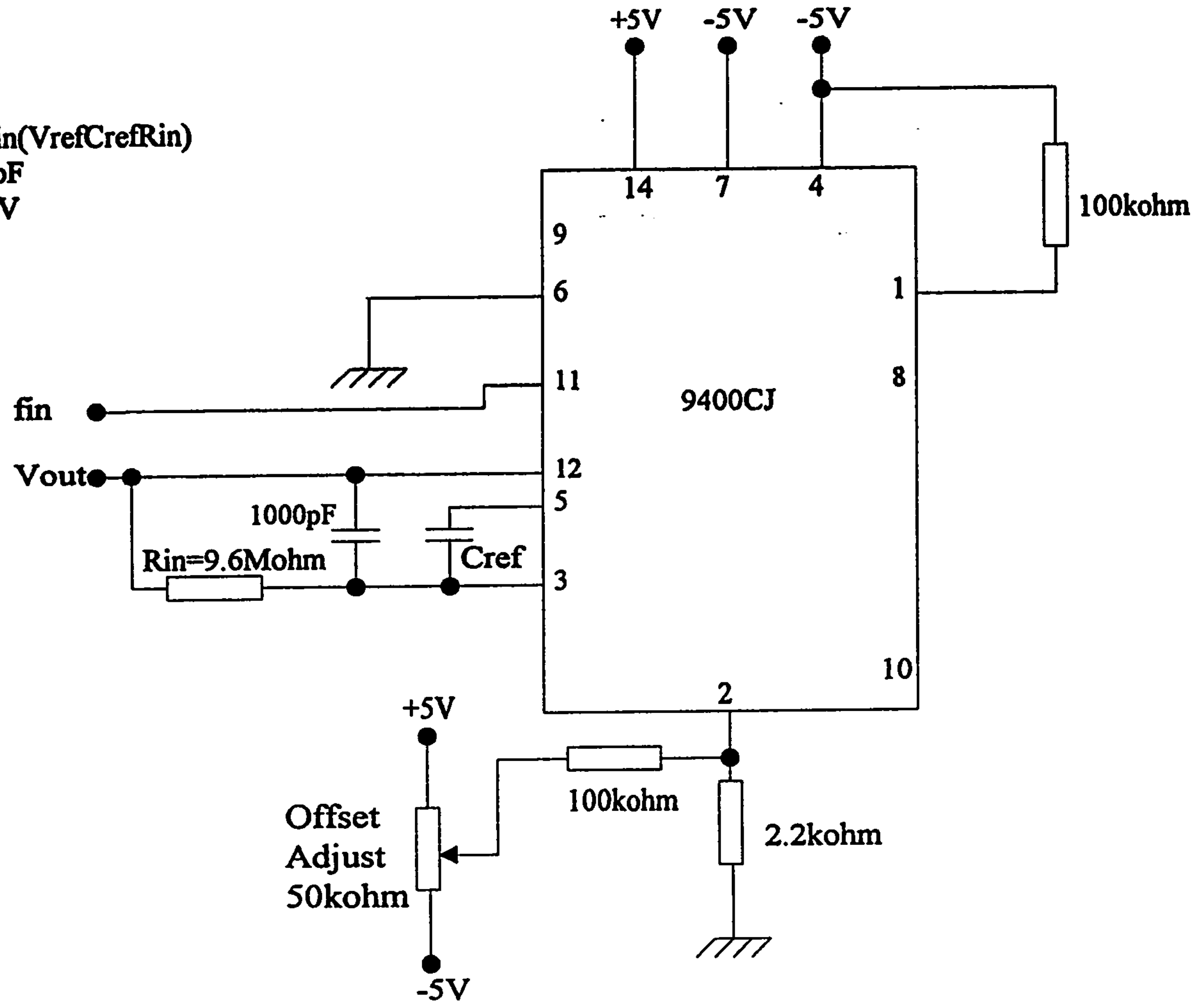


FIGURE 5.9
Frequency to Voltage Converter for Flowmeter

The output dc voltage is given by

$$V_{out} = 2 f_{in} \times V_{ref} \times C_{ref} \times R_{in} \tag{5.2}$$

where

f_{in} = the flow meter frequency
V_{ref} = the reference voltage $= 5V$
C_{ref} = the reference capacitor $= 39pF$
R_{in} = the input resistance $= 9.6M\Omega$

The maximum output frequency out of the flow meter is 500Hz. Therefore, the ADC resolution is given by

$$V_{out,max} = 2 \times 500 \times 5 \times 39 \times 10^{-12} \times 9.6 \times 10^{6} = 1.872 V_{dc}$$

$$\text{ADC resolution} = \frac{V_{out,max}}{2^{11}} = 0.914 mV / level \tag{5.3}$$

The fluid flow is controlled by a pump (replacing the solenoid valve). This pump is controlled by the computer using a relay, which connects or disconnect the power supply (127 Vac).

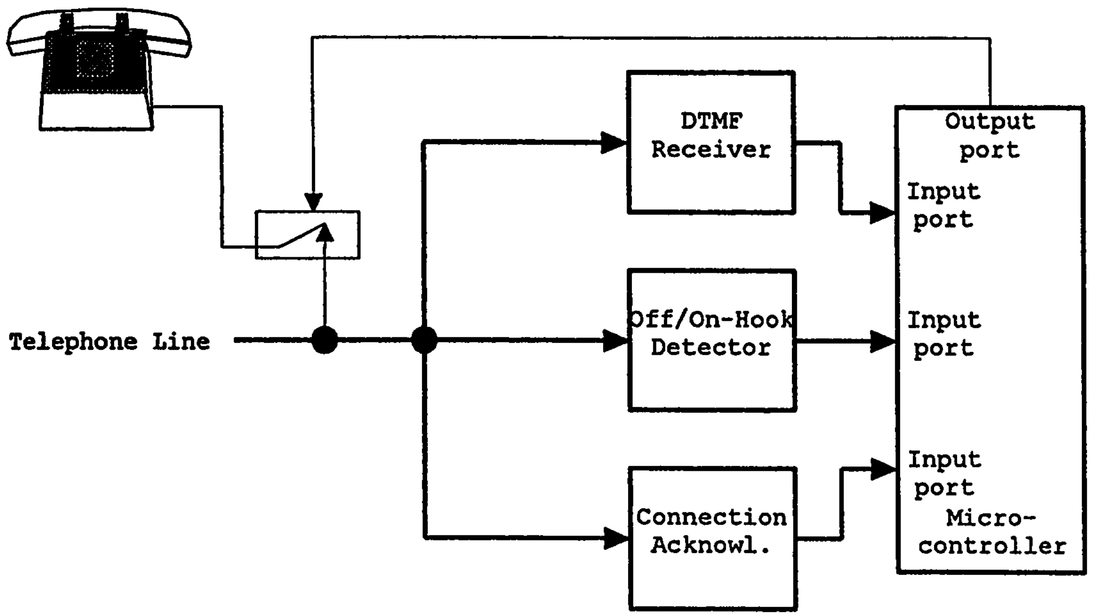
The calibration of this circuit is done by having a constant flow. Comparing the frequency read by the oscilloscope to the frequency read by the proposed circuit, the prposed circuit can be accordingly tuned to meet the reading by the oscillosope.

5.5 TELEPHONE CALL METER IMPLEMENTATION

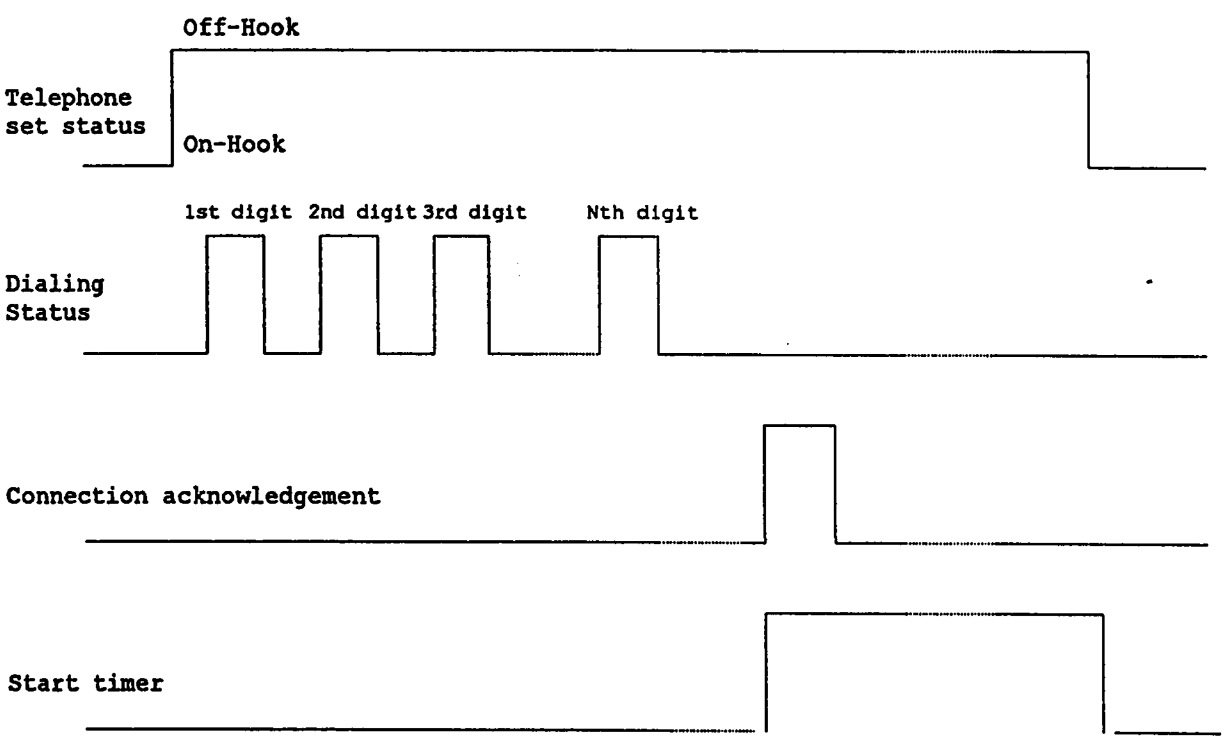
Althogh, the following describes the telephone call meter that uses the battery interuption or battery reversal technique, it, also, applicable for the coin pulse detection technique. The designed circuit is based on the Dual Tone Multifrequency (DTMF) Signals that can be produced by the telephone set and sent from one end through the loop wire to the destination. The circuit consists of an off/on hook detector and a DTMF receiver. The data base for the access codes and associated charges are stored in a permanent storage (e.g. EEPROM) for calculating calls charges. The general block and the timing diagrams are shown in Figure 5.10.

5.5.1 PRINCIPLES OF TONE DIALING

Most of the telephone sets use the method called dual tone multifrequency (DTMF) for sending a telephone number. As shown in Figure 5.11, these telephone sets are equipped with a push-button keypad with 12 keys which represent the numbers 0 through 9 and the symbols * and #. Pressing one of the keys causes the DTMF generator to generate two tones in



(a)



(b)

FIGURE 5.10, a) TELEPHONE CALLS CIRCUIT BLOCKS b) PROCEDURE TIMING

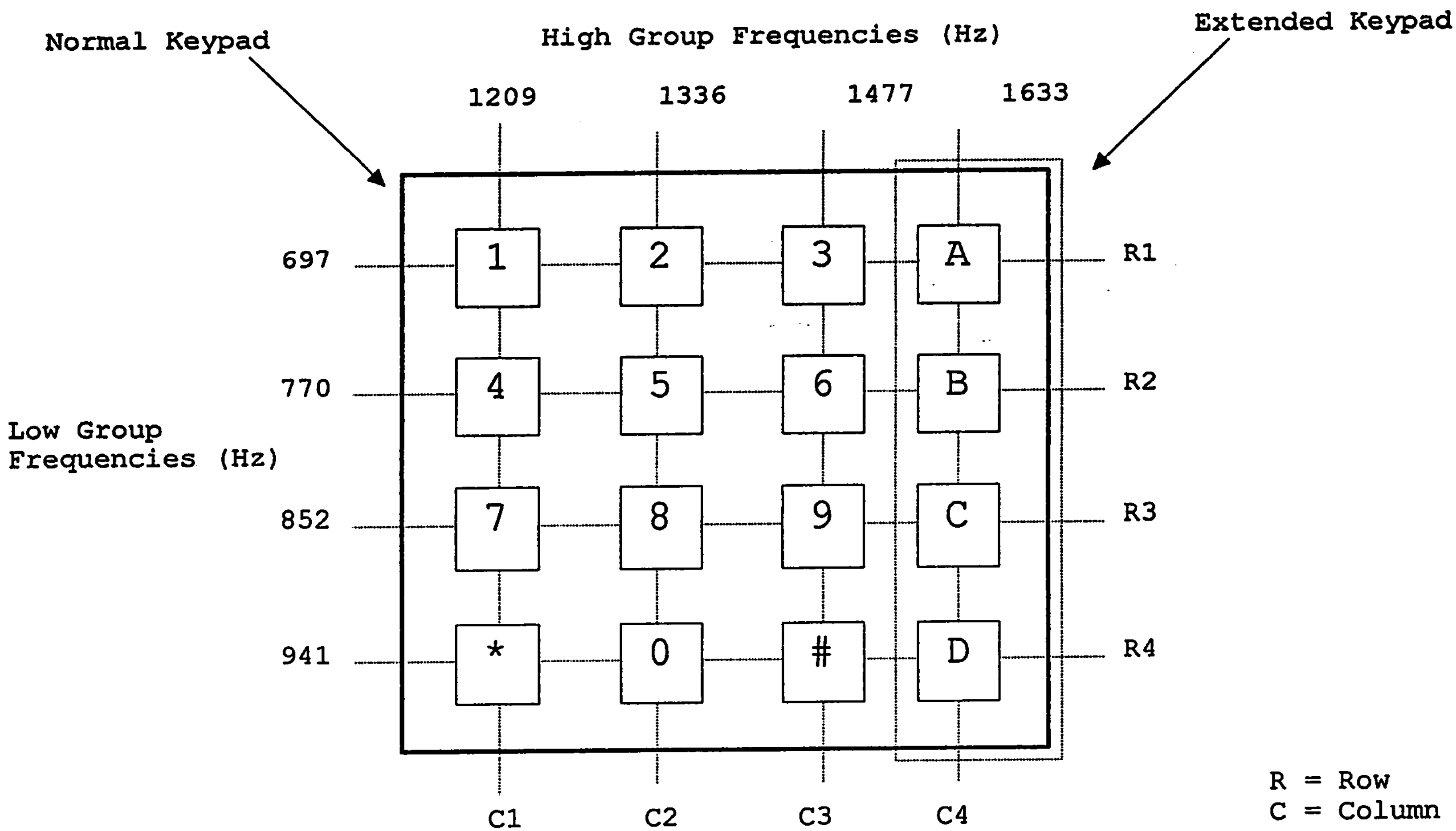


Figure 5.11
DTMF Keypad and Frequencies

the voice band (300 - 3,000 Hz). There is a low frequency tone for each row and a high frequency tone for each column. Pressing key 5, for example, generates a 770 Hz tone and a 1,336 Hz tone. By using the dual tone method, 12 unique combinations are produced from only seven tones when the 12 position keypad is used [9].

The frequencies and the keypad layout have been internationally standardized, but the tolerances on individual frequencies may vary in different countries. The North American standards is ±1.5% for the generator and ±2.0% for the receiver.

The tones have been selected carefully so that the DTMF receiver at the central office will not confuse them with other tones (signaling tones) that may occur on the line.

5.5.2 DTMF RECEIVER CIRCUIT DESIGN

The task of the DTMF Receiver is to detect the presence of a valid tone pair on a telephone line or other transmission medium.

The presence of a valid tone pair indicates a single dialed digit; to generate a valid digit sequence, each tone pair must be separated by a valid pause.

The following table gives the established Bell system standards for a valid tone pair and a valid pause:

One Low-Group Tone	697 or 770 or 852 or 941 Hz
One High-Group Tone	1209 or 1336 or 1477 or 1633 Hz
Frequency Tolerance	f_o (1.5% + 2 Hz)
Amplitude Range	-24 dBm < A < +6 dBm @ 600 Ohm
Tone Duration	40 ms or longer
Pause Duration	40 ms or longer

Figure 5.12 shows the complete circuit for the DTMF receiver. The circuit employs the Radio-Shak (276-1303) DTMF Receiver. Which is a complete Dual Tone Multifrequency (DTMF) Receiver detecting a selectable group of 12 or 16 standard digits. A description of the DTMF receiver is provided in Appendix H.

As shown in Figure 5.12, the circuit is configured as follows:

THE INPUT STAGE:

The input pins 9 & 10 are connected to the Isolator transformer which is used to isolate the telephone line ground from the digital ground. Pin 10 is tied to the digital ground, which is the ground input.

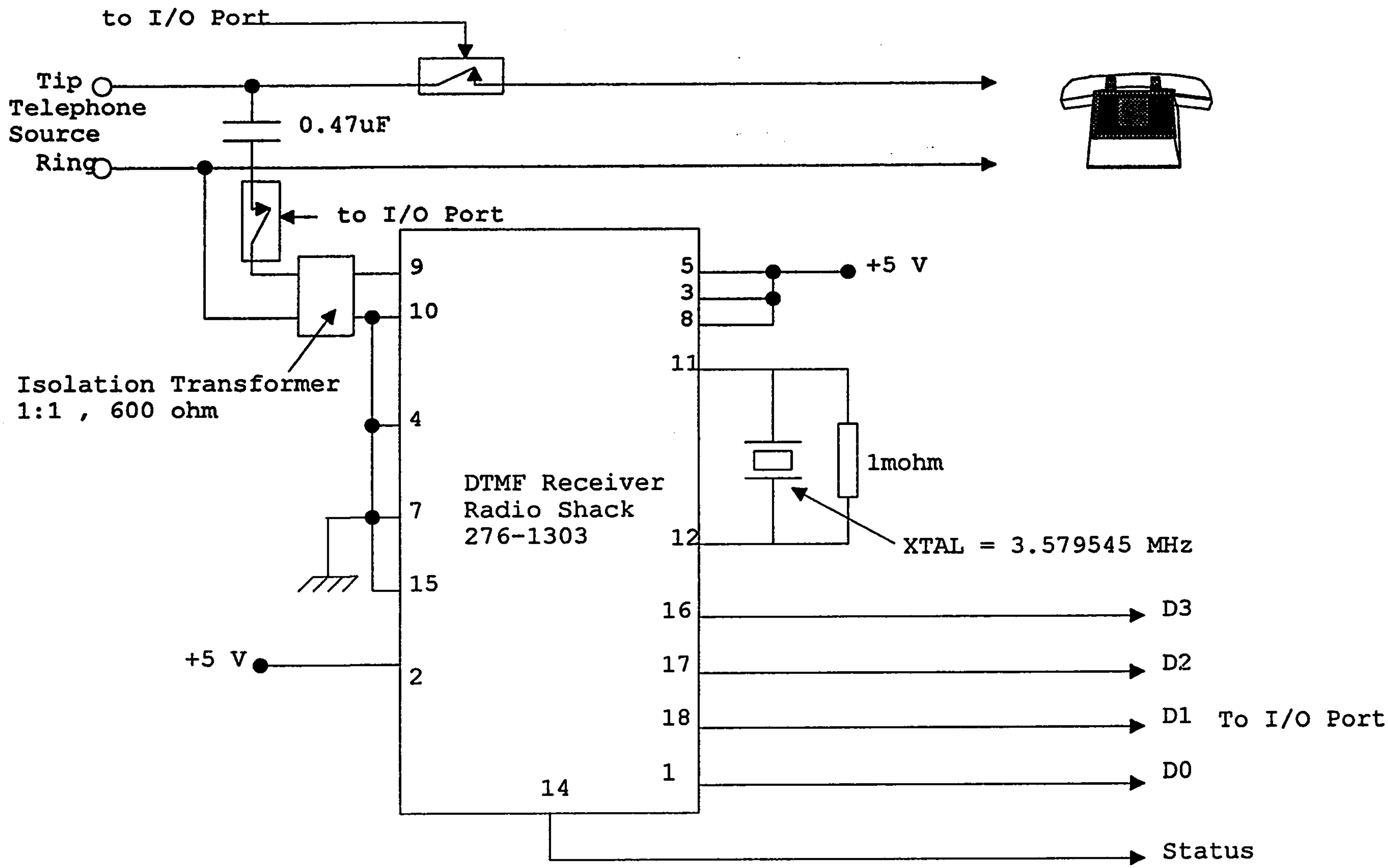


FIGURE 5.12
DTMF RECEIVER AND TELEPHONE LINE CONTROLLER

Then, the Ring terminal of the telephone line is connected to one terminal of the Isolation transformer and the other terminal is connected to one end of the relay. The other end of the relay is connected to one terminal of a capacitor, which allows AC signal to pass through. The second terminal of the capacitor is connected to the Tip terminal of the telephone line.

The relay provides the control of connecting the DTMF receiver to the telephone line via the PC. Also, it protects the DTMF receiver from the ring signals that could damage it. The ring signals are in the range 40 to 130 Vrms and 16 to 60 Hz. The typical U.S. values are 90 Vrms and 20 Hz.

THE OUTPUT STAGE:

Pin 4 is tied to the ground to enable the detection of tone pairs containing the 1633 Hz component, for detection all 16 standard digits. Pin 2 is tied to high, which means the output is in hexadecimal. Pin 3 is tied to high, which configures the outputs to be push pull. The outputs pins 1, 16, 17 and 18, and the data valid (status) pin 14 are connected to the Hexinverter and to the I/O interface for processing as shown in Figure 5.13.

OTHER PINS:

Pin 7 is the chip ground tied to the digital ground. The digital ground is provided from I/O interface. Pin 15

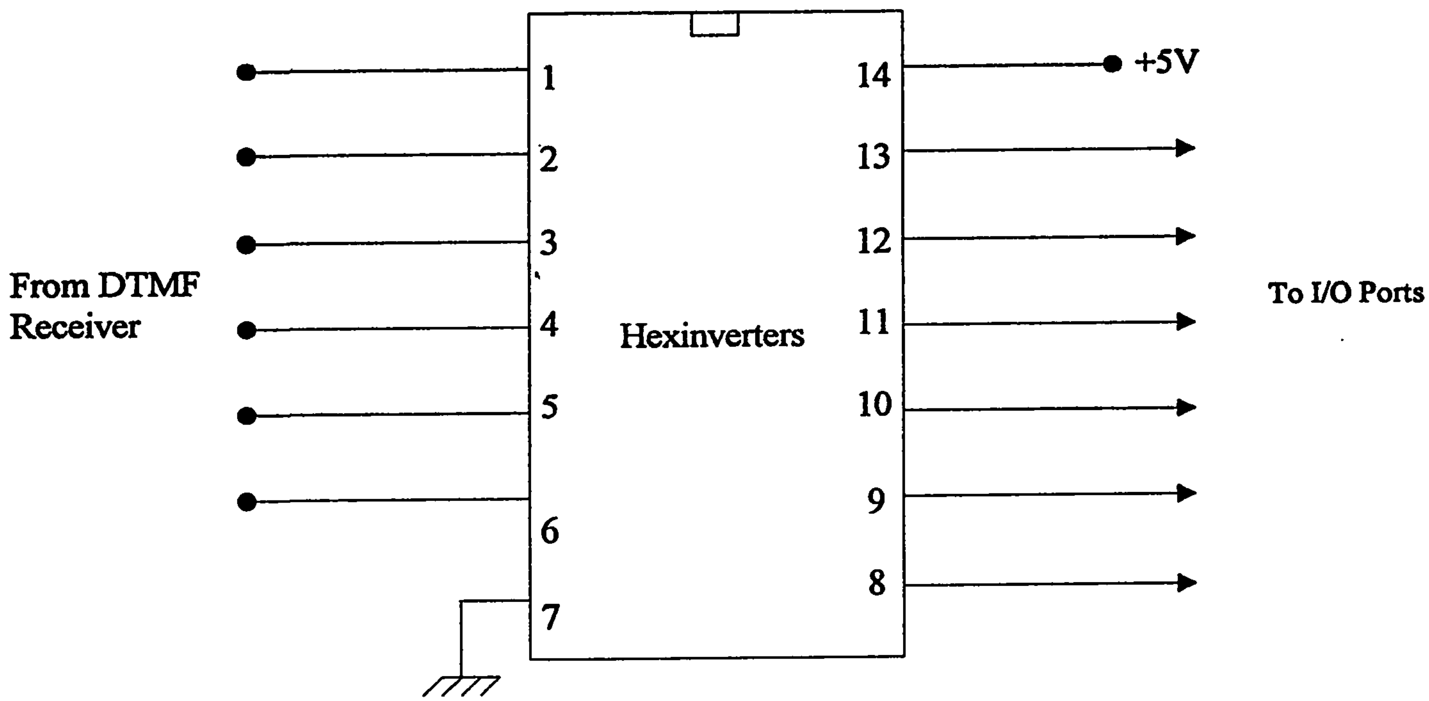


FIGURE 5.13
Hexinverter Circuit (7404)

(CLRDV) tied to the digital ground which means that the data Valid (DV) is cleared by a valid pause only. Pin 5 is the chip power supply (+5) which is provided from I/O interface. Pin 8 is tied to high, which is the crystal enable. Pin 11 & 12 are the crystal connection.

5.5.3 OFF/ON HOOK DETECTOR CIRCUIT

Figure 5.14 shows the circuit connections. The circuit makes use of an Optoisolator component to indicate the off/on hook telephone status.

THE INPUT STAGE:

The input stage pins 1 & 2 of the optoisolator consists of an LED (light emitting diode). These two pins are connected to a diode to prevent from reverse DC voltages. Then, pin 2 is connected to the Ring of the telephone line. Pin 1 is connected to 10 kohm and a potentiometer of 20 kohm to adjust the sensitivity. Then, the end terminal is connected to the Tip side of the telephone line.

The forward current for the LED is 1 to 20 mA. Therefore, the operating current has been chosen to be 4 mA.

The common battery voltage from the CO $= 50 \pm 2Vdc$

123

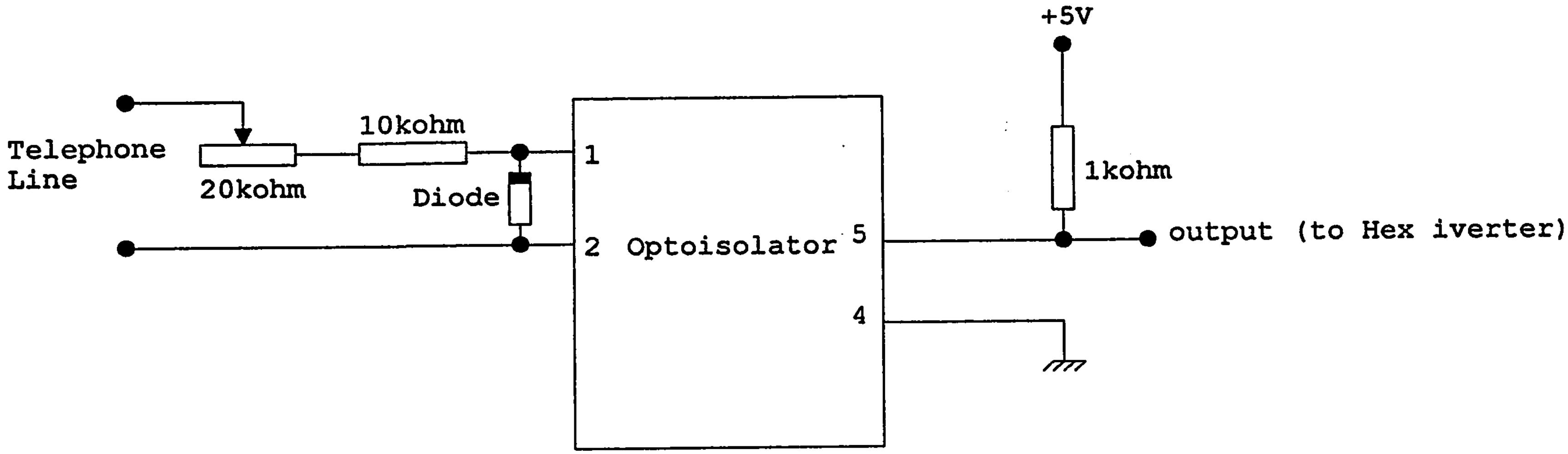


FIGURE 5.14
OFF/ON HOOK DETECTOR

$\rightarrow Bat. = 50Vdc$

$$I_f = \frac{Bat. - 0.7}{R}$$

$I_f(\text{choosen}) = 4mA$

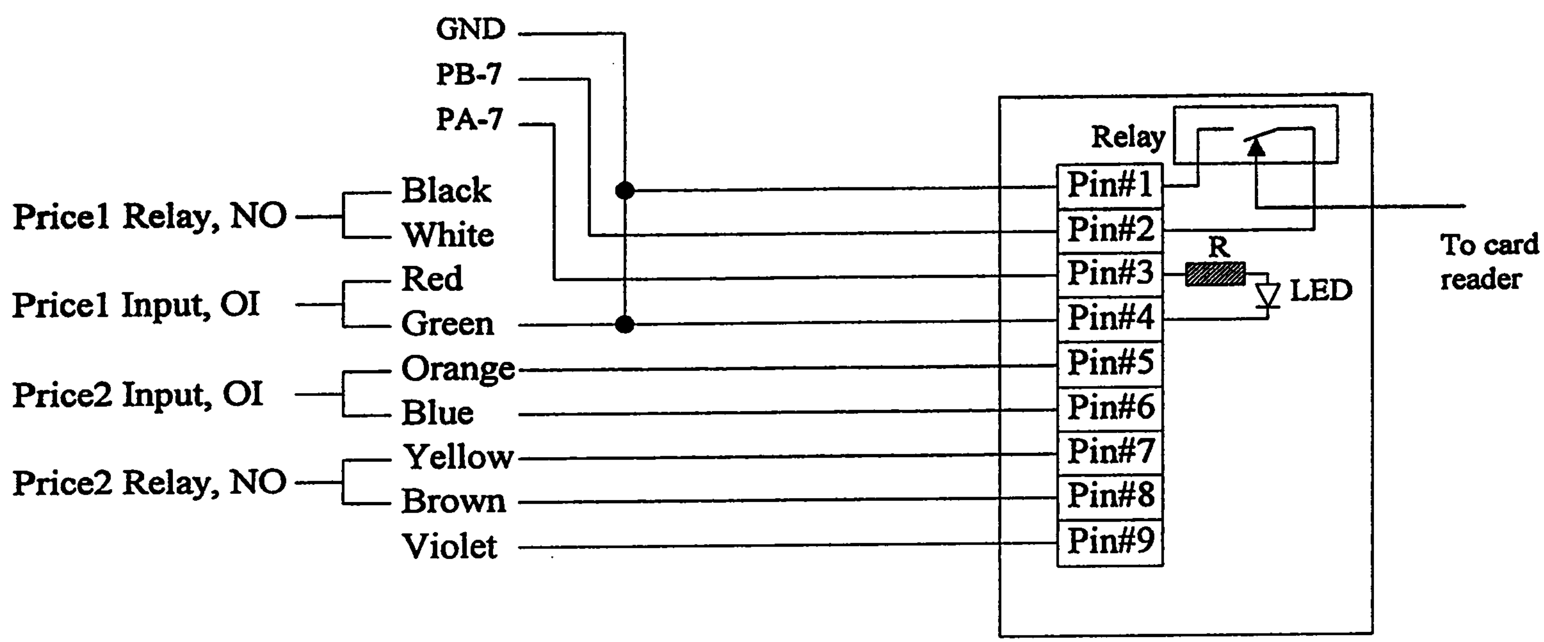
$$\Rightarrow R = \frac{Bat. - 0.7}{I_f} = \frac{50 - 0.7}{4 \times 10^{-3}} = 12.325k\Omega$$

THE OUTPUT STAGE:

The output stage pins 4 & 5 of the optoisolator consists of a photo-transistor, which is connected to a resistor of 1 kohm. The end of the resistor is connected to +5V from the I/O interface. Pin 4 is connected to the ground. Then, pin 5 is connected to the Hexinverter from which to the I/O interface.

5.6 CARD READER INTERFACE

The card reader realization is made of a ready system which is modified and interfaced to the system. The connection circuit is shown in Figure 5.15. When a magnetic-card is inserted in the card reader and if the card has a credit, a relay is switched on and closes the two terminals. Therefore, a card-in indication is done by connecting one terminal of the relay to the ground and the other end to an input port. Inserting a card will pull the input port to the ground.



Notes:

1. Relays are normally open (NO), switching rate < 0.5 A @ 32 Vdc
2. Opto-isolator (OI) input < 32 Vac/dc.

FIGURE 5.15
Card Reader Harness Interface
Installation

When the card reader receives a pulse from the LED, the amount of credit on the magnetic-card is deducted by one unit. Therefore, generating pulses on the LED and monitoring the card-in terminal, the credit amount on the magnetic-card can be serially loaded and stored in the computer. The pulse is generated by connecting one terminal of the LED to the ground and the other terminal to an output port. Pulling the output port to +5V and then to the GND, a pulse is generated on the LED. The loading speed is controlled by the speed of the pulse.

5.7 I/O INTERFACE CARD

The system circuits are connected to the computer via an interface card. This card is used to provide the followings:

- A/D converters: 12-bit, $\pm 10V$.
- Three 8-bit Input/Output ports: Port A, B & C.
- Three 16-bit timers: Timer 0, 1 & 2.
- Digital ground, +5 V & -5 V.

The different card addresses are given in Tables 5.1&2. Full information of the I/O circuit is presented in Appendix D.

IBM - PC Interface
D - Connector
25 - Pin

		Data bits									
		Binary								Hex	Decimal
Pin#	Used for	D7	D6	D5	D4	D3	D2	D1	D0		
1	PB6	0	1	0	0	0	0	0	0	40	064
2	PB5	0	0	1	0	0	0	0	0	20	032
3	PB4	0	0	0	1	0	0	0	0	10	016
4	PB3	0	0	0	0	1	0	0	0	08	008
5	PB7	1	0	0	0	0	0	0	0	80	128
6	PB2	0	0	0	0	0	1	0	0	04	004
7	PB1	0	0	0	0	0	0	1	0	02	002
8	PB0	0	0	0	0	0	0	0	1	01	001
9	*OUT0										
10	*CLK0										
11	*GATE1										
12	*OUT2										
13	PC4	0	0	0	1	0	0	0	0	10	016
14	PC5	0	0	1	0	0	0	0	0	20	032
15	PC6	0	1	0	0	0	0	0	0	40	064
16	PC7	1	0	0	0	0	0	0	0	80	128
17	PA0	0	0	0	0	0	0	0	1	01	001
18	PA1	0	0	0	0	0	0	1	0	02	002
19	PA2	0	0	0	0	0	1	0	0	04	004
20	PA3	0	0	0	0	1	0	0	0	08	008
21	PA7	1	0	0	0	0	0	0	0	80	128
22	PA6	0	1	0	0	0	0	0	0	40	064
23	PA5	0	0	1	0	0	0	0	0	20	032
24	PA4	0	0	0	1	0	0	0	0	10	016
25	volt (+5)										
D-Metal	GND										

Notes:
1. PC1 used for Gate-2 (Timer)
2. PC3 used for Gate-0 (Timer)
3. PC2 is used for CLK1 and PC7 is used for GATE1

* These are wired to the timer (8253), others are connected to I/O ports (8255)

Table 5.1

Control Word Bits Assignment
For I/O 8255

Binary								Hex	Dec.		Function		
D7	D6	D5	D4	D3	D2	D1	D0			Port C-U	Port A	Port B	Port C-L
1	0	0	PC-U	PA	0	PB	PC-L						
1	0	0	0	0	0	0	0	80	128	output	output	output	output
1	0	0	0	0	0	0	1	81	129	output	output	output	input
1	0	0	0	0	0	1	0	82	130	output	output	input	output
1	0	0	0	0	0	1	1	83	131	output	output	input	input
1	0	0	0	1	0	0	0	88	136	output	input	output	output
1	0	0	0	1	0	0	1	89	137	output	input	output	input
1	0	0	0	1	0	1	0	8A	138	output	input	input	output
1	0	0	0	1	0	1	1	8B	139	output	input	input	input
1	0	0	1	0	0	0	0	90	144	input	output	output	output
1	0	0	1	0	0	0	1	91	145	input	output	output	input
1	0	0	1	0	0	1	0	92	146	input	output	input	output
1	0	0	1	0	0	1	1	93	146	input	output	input	input
1	0	0	1	1	0	0	0	98	152	input	input	output	output
1	0	0	1	1	0	0	1	99	153	input	input	output	input
1	0	0	1	1	0	1	0	9A	154	input	input	input	output
1	0	0	1	1	0	1	1	9B	155	input	input	input	input

	Port	Address Binary	Hex	Dec.	Function
I/O	Port A	B0000001100000000	300	768	R/W
8	Port B	B0000001100000001	301	769	R/W
2	Port C-L	B0000001100000010	302	770	R/W
5	Port C-U	B0000001100000011	302	770	R/W
5	Ctrl Wrd	B0000001100000100	303	771	R/W
8	TCount-0	B0000001100000101	304	772	Read and Load
2	TCount-1	B0000001100000110	305	773	Read and Load
5	TCount-2	B0000001100000111	306	774	Read and Load
3	TWrt-Mod	B0000001100001000	307	775	Operation mode

Notes:

> Control Word for Timer 8253 normally 54D (36H, 00110110B) which is Binary counting, Read/Load least significant byte first then most significant byte.

Table 5.2

5.8 SYSTEM INTEGRATION

The integrated system is constructed inside a box, which is connected to the computer via a 25-pin D-shell connector. The implemented system is shown in Figures 5.16a&b. The front switches are used to connect the external +5Vdc, electric ac line, and telephone line. The front outlets are used to distribute the telephone line and electric ac line. Also, one ac outlet is used for the water/gas pump.

5.9 SOFTWARE DEVELOPMENT

Two programs were developed for demonstration. The first program is written for system maintenance, to test and evaluate each utility meter separately under different parameters. The second is an integrated software package which is developed to operate and command the overall system. The programs were written to communicate with the implemented circuits shown in Figures 5.16a&b. Figures 5.17a, b, c, d & e show the flowcharts for the programs used in the prototype system. The programs were written using Turbo Basic and Assembly languages. The followings summarize the objectives of the programs:

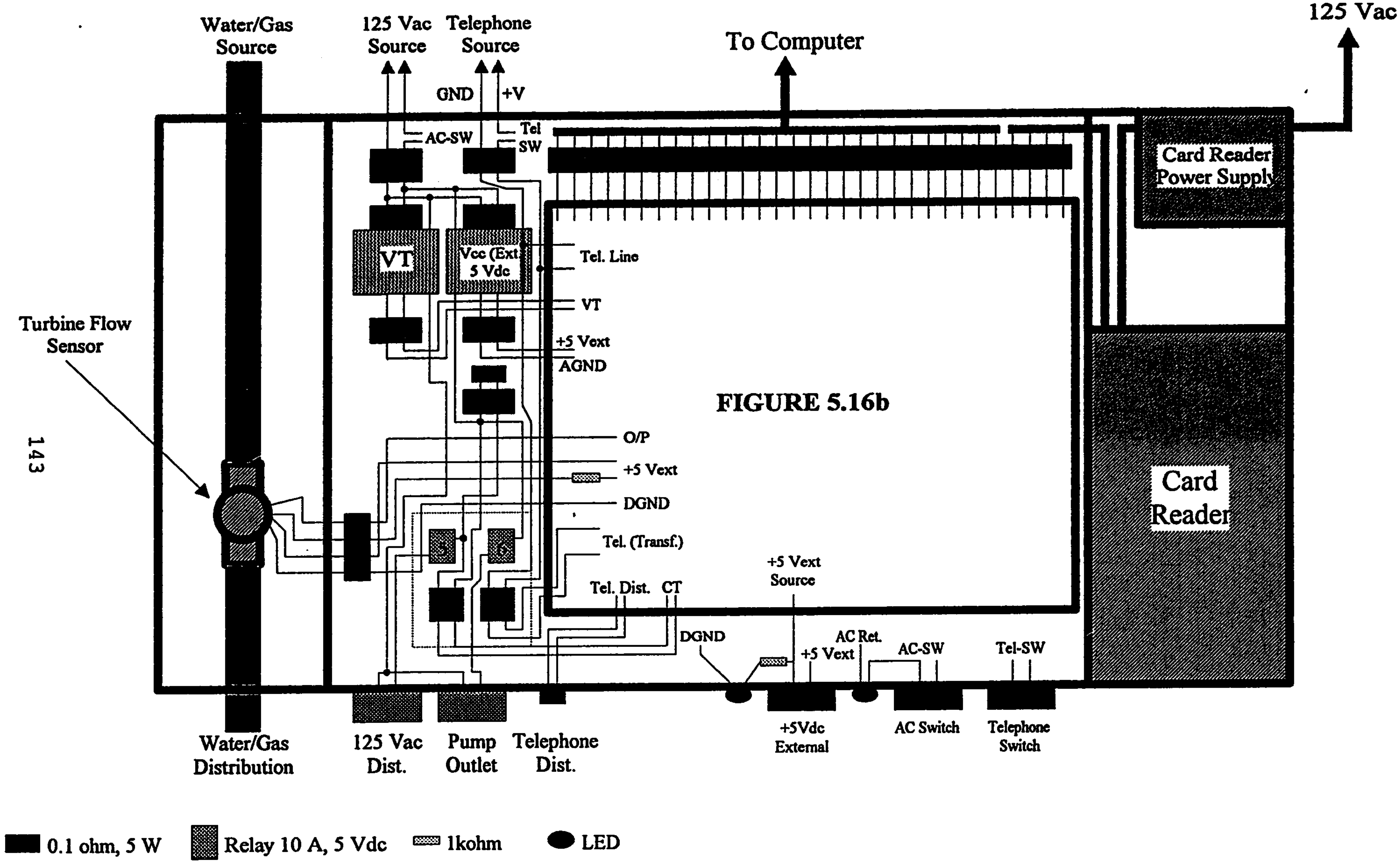

Water/Gas
Source
125 Vac
Source
Telephone
Source
GND
+V
To Computer
125 Vac
AC-SW
Tel
SW
Card Reader
Power Supply
VT
Vcc (Ext
5 Vdc
Tel. Line
VT
+5 Vext
AGND
FIGURE 5.16b
Turbine Flow
Sensor
O/P
+5 Vext
DGND
Tel. (Transf.)
Card
Reader
5
6
Tel. Dist.
CT
+5 Vext
Source
DGND
AC Ret.
+5 Vext
AC-SW
Tel-SW
Water/Gas
Distribution
125 Vac
Dist.
Pump
Outlet
Telephone
Dist.
+5Vdc
External
AC Switch
Telephone
Switch
0.1 ohm, 5 W
Relay 10 A, 5 Vdc
1kohm
LED

FIGURE 5.16a

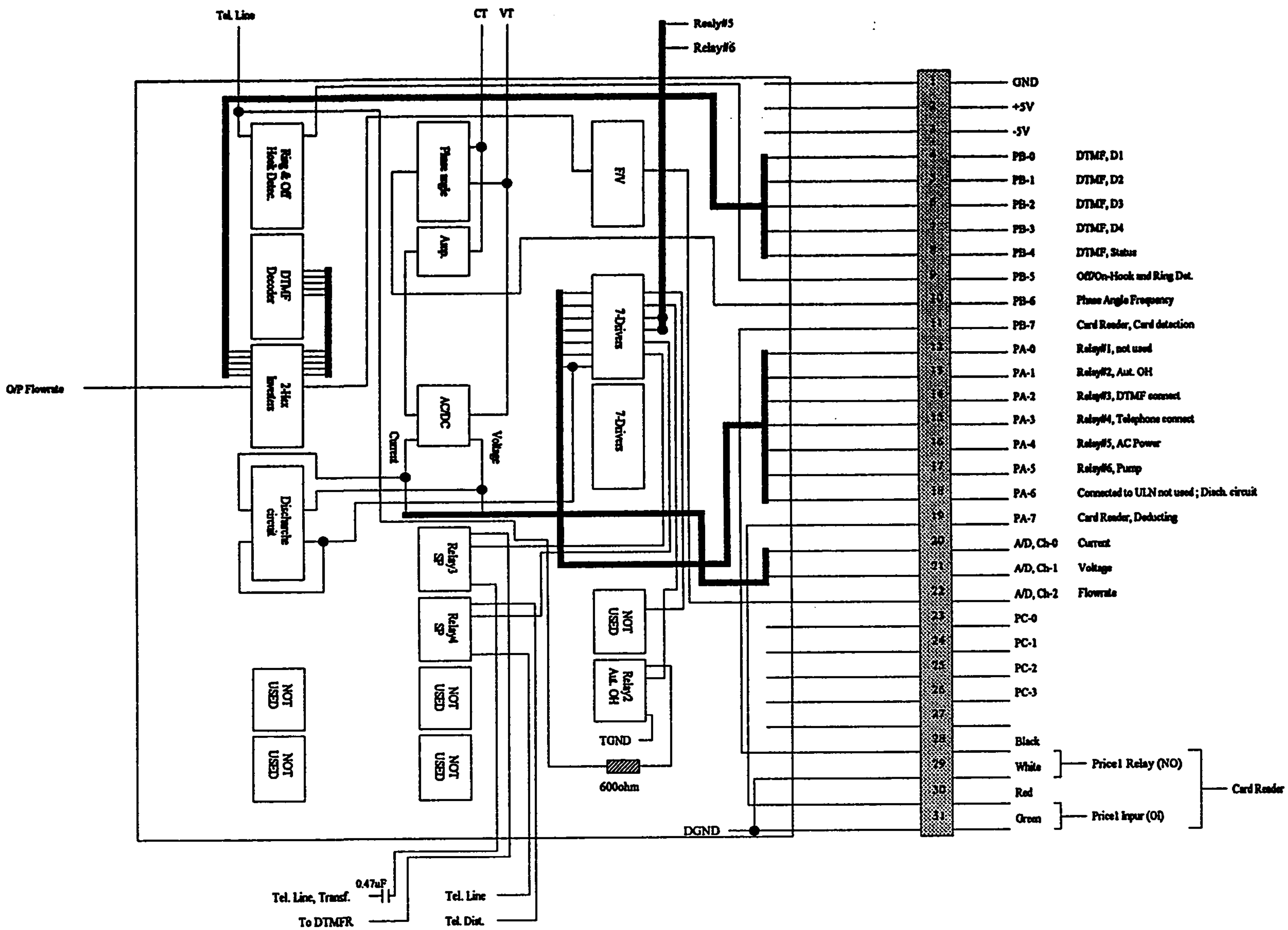

Tel. Line
CT VT
Realy#5
Relay#6
Ring & Off Hook Detec.
DTMF Decoder
2-Hex Inverters
Discharche circuit
Phase angle
Amp.
AC/DC
Current
Voltage
F/V
7-Drivers
7-Drivers
Relay3 SP
Relay4 SP
NOT USED
NOT USED
NOT USED
NOT USED
NOT USED
Relay2 Aut. OH
TGND
600ohm
DGND
O/P Flowrate
0.47uF
Tel. Line, Transf.
To DTMFR
Tel. Line
Tel. Dist.
GND
+5V
-5V
PB-0 DTMF, D1
PB-1 DTMF, D2
PB-2 DTMF, D3
PB-3 DTMF, D4
PB-4 DTMF, Status
PB-5 Off/On-Hook and Ring Det.
PB-6 Phase Angle Frequency
PB-7 Card Reader, Card detection
PA-0 Relay#1, not used
PA-1 Relay#2, Aut. OH
PA-2 Relay#3, DTMF connect
PA-3 Relay#4, Telephone connect
PA-4 Relay#5, AC Power
PA-5 Relay#6, Pump
PA-6 Connected to ULN not used ; Disch. circuit
PA-7 Card Reader, Deducting
A/D, Ch-0 Current
A/D, Ch-1 Voltage
A/D, Ch-2 Flowrate
PC-0
PC-1
PC-2
PC-3
Black
White
Red
Green
Price1 Relay (NO)
Price1 Inpur (OI)
Card Reader

FIGURE 5.16b

- Reads all variables from the circuits: voltage, current , pf, off/on hook, dialed numbers, telephone connection and flow rate frequency.
- Loads credit value from the card reader.
- Calculates: real power, calls period and flow rate.
- Calculates the chargers and stores them in memory.
- Displays all variables on screen.
- Generates alarm for overdue, overload or any system failure.
- Controls the electric, telephone and water/gas sources. If the customer has a bad credit, the service will be disconnected, automatically.
- Deducts the charges from the cards.

The Basic and Assembly programs are listed in Appendices A, B&G. In the following subsections, an explanation of the different routines is presented.

5.9.1 INITIALIZATION ROUTINE (Figure 5.17a)

The initialization routine does the followings:

1. I/O ports are initialized by configuring Port A&C as an output, and Port B as an input.

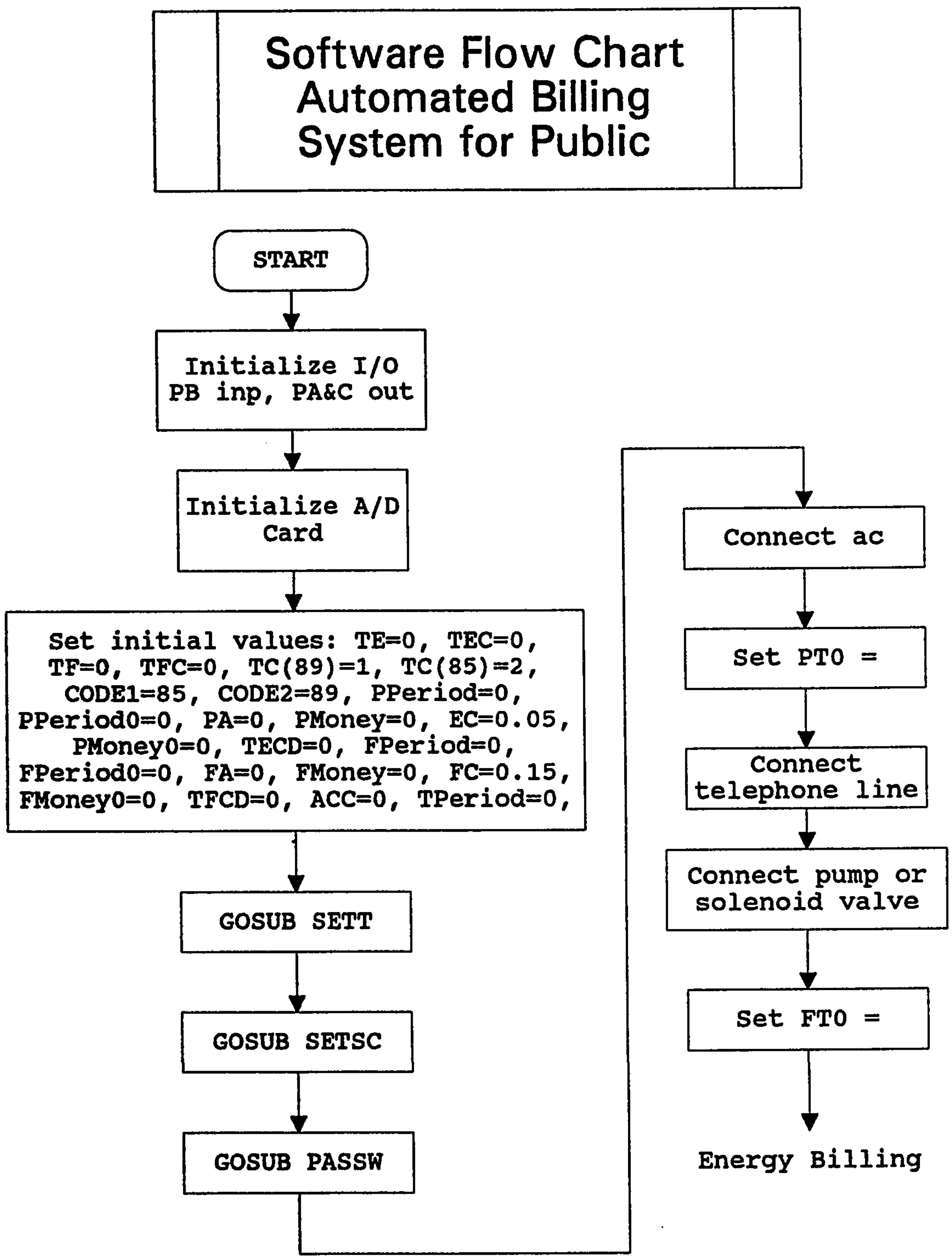

Software Flow Chart
Automated Billing
System for Public
START
Initialize I/O
PB inp, PA&C out
Initialize A/D
Card
Set initial values: TE=0, TEC=0,
TF=0, TFC=0, TC(89)=1, TC(85)=2,
CODE1=85, CODE2=89, PPeriod=0,
PPeriod0=0, PA=0, PMoney=0, EC=0.05,
PMoney0=0, TECD=0, FPeriod=0,
FPeriod0=0, FA=0, FMoney=0, FC=0.15,
FMoney0=0, TFCD=0, ACC=0, TPeriod=0,
GOSUB SETT
GOSUB SETSC
GOSUB PASSW
Connect ac
Set PTO =
Connect
telephone line
Connect pump or
solenoid valve
Set FTO =
Energy Billing

FIGURE 5.17a

2. A/D converters are initialized and configured to accept a voltage input range of $-10V$ to $+10V$.

3. System parameters are set with initial values.

4. A password for system operation is prompted.

5. The time and date are set to reflect the current time and date.

6. The display screen is formatted to reflect the different readings.

7. The ac source is connected to the customer.

8. The power initial time (PT0) is set to the current time.

9. The telephone line source is connected to the customer.

10. The water/gas source is connected to the customer.

11. The flow initial time (FT0) is set to the current time. Then, energy routine is executed.

5.9.2 CREDIT LOADING ROUTINE (Figure 5.17b)

The credit loading routine does the followings:

1. The card is checked for availability. If the card is in the card reader, the accumulator (ACC) value is incremented by one. However, if not, the routine is terminated and return.

2. The credit value in the card is deducted by one.

3. The routine loops back to step 1.

5.9.3 ENERGY BILLING ROUTINE (Figure 5.17c1)

The energy billing routine does the followings:

1. The power alarm (PA) is checked. If PA is activated, the flow routine is executed. However, if not, step 2 is fetched.

2. If the credit that is available for ac power (PMoney) is greater than the total energy cost to be deducted (TECD), the energy calculation routine is executed. If not, step 3 is fetched.

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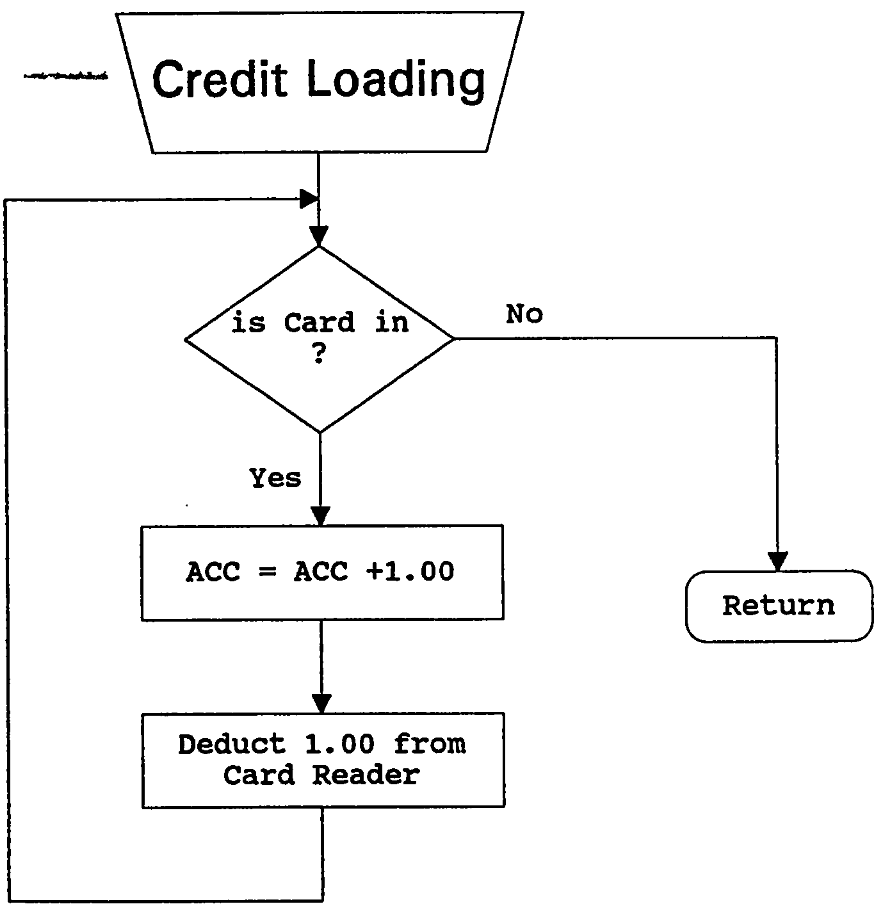
Credit Loading
is Card in ?
No
Yes
ACC = ACC +1.00
Return
Deduct 1.00 from Card Reader

FIGURE 5.17b

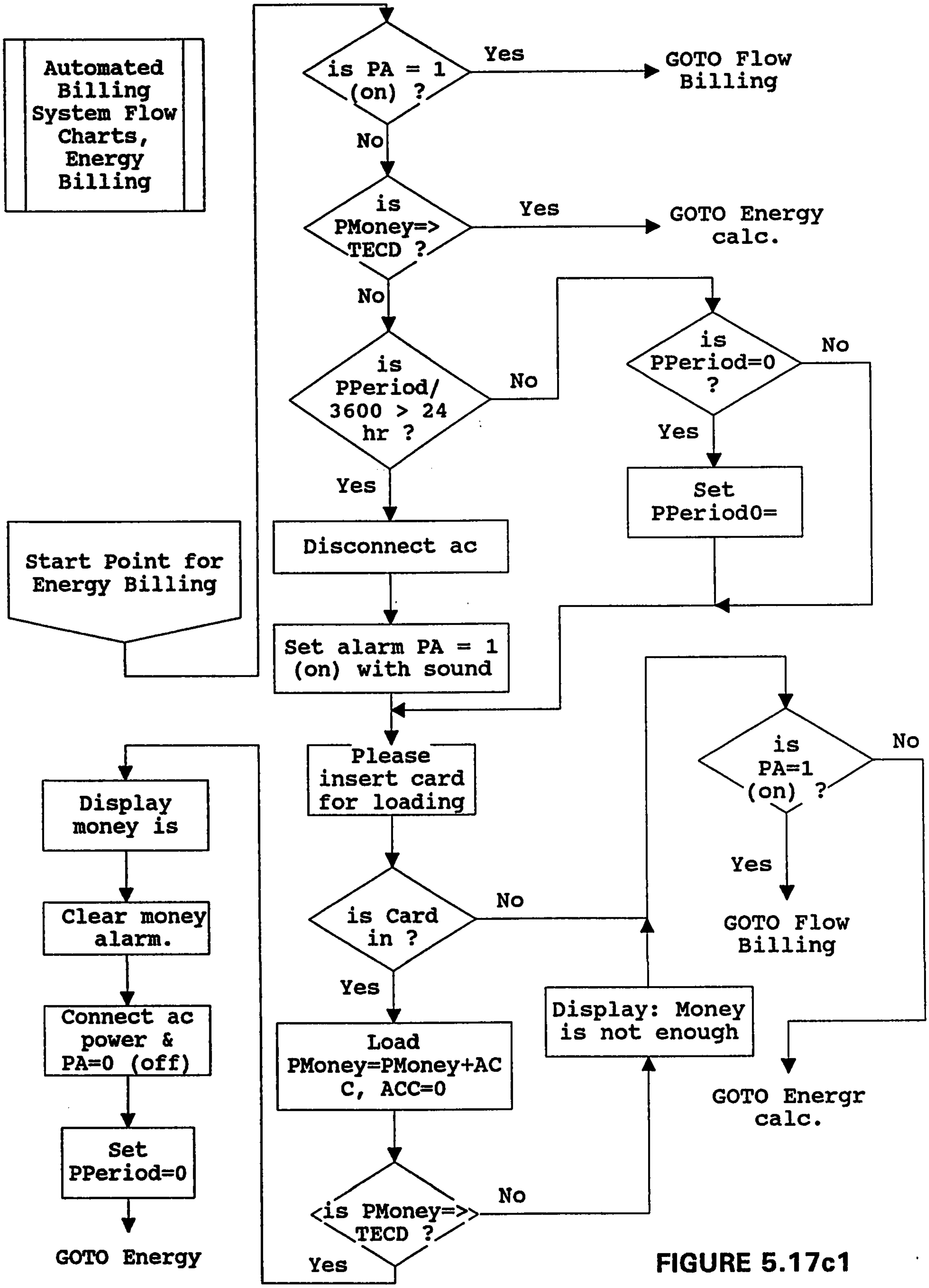

FIGURE 5.17c1

3. The grace period is checked. If the power period (PPeriod) is less than 24hr, step 4 is fetched. If not, the ac power is disconnected, the power alarm is set, and card insertion is prompted. Then, step 5 is fetched.

4. If PPeriod is equal to zero, the initial PPeriod (PPeriod0) is set to the current time and card insertion is prompted. If not, card insertion is prompted.

5. If a card is inserted, the credit amount is loaded, PMoney is incremented by ACC, ACC is set to zero, and step 7 is executed.

6. If a card is not inserted and if PA is set to one, the flow routine is executed. If PA is set to zero, the energy calculation is executed.

7. If PMoney is greater than or equal to TECD, credit availability is displayed, credit alarm is cleared, ac power is connected, PA and PPeriod are set to zero, and energy calculation routine is executed.

8. If PMoney is less than TECD, low credit is displayed, PA is set to one, and step 6 is fetched.

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5.9.4 ENERGY CALCULATION ROUTINE (Figure 5.17c2)

The energy calculation routine does the followings:

1. The voltage, current, and power factor angle are measured. The average power is calculated for a period of time (T).

2. Energy (E) and the total energy (TE) are calculated and displayed.

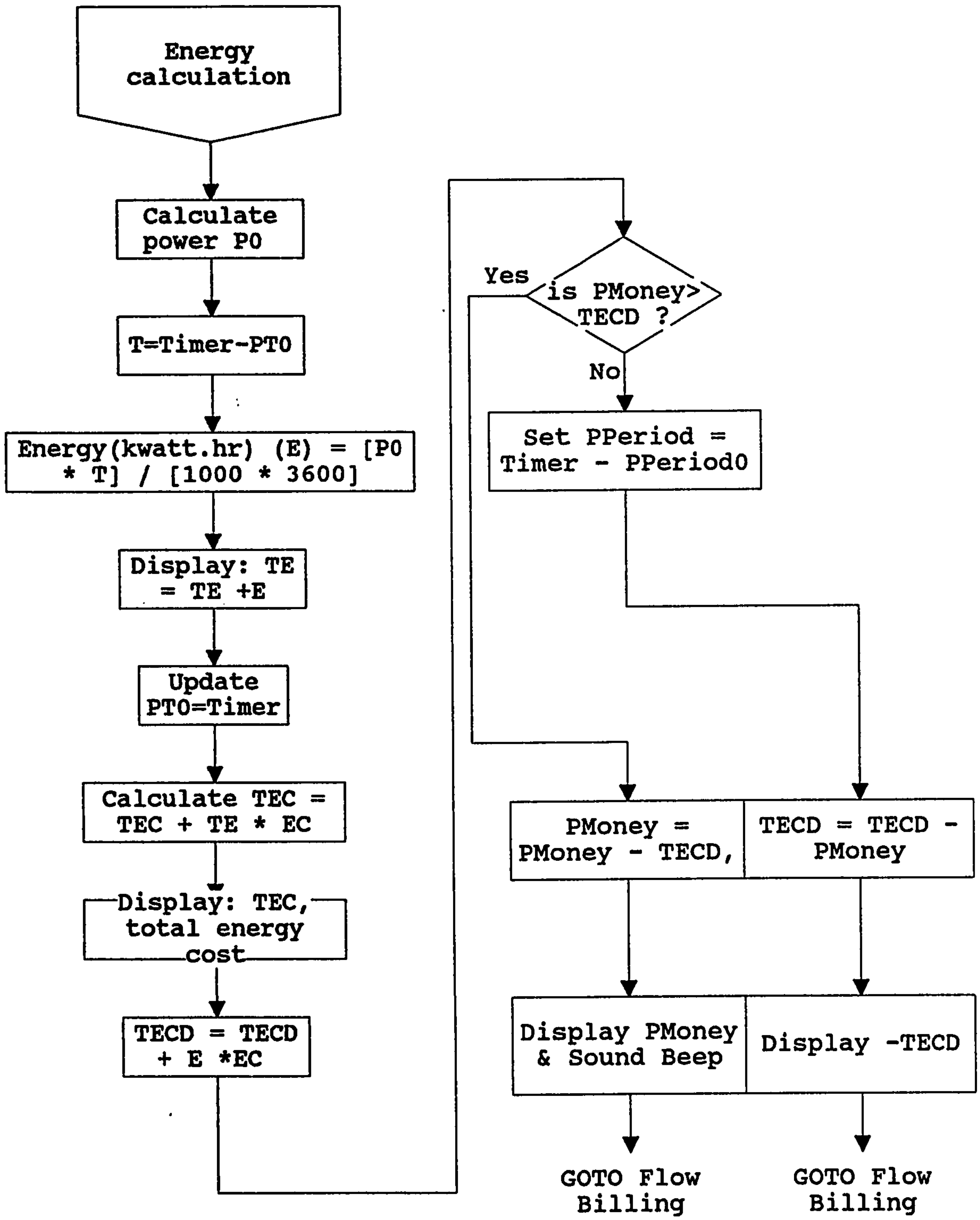
3. PT0 is initialized with the current time. The total energy costs (TEC) and TECD are calculated.

4. If PMoney is less than TECD, the PPeriod is set to current timer minus PPeriod0, PMoney is deducted from TECD, and TECD is displayed. Then, flow billing routine is executed.

5. If PMoney is greater or equal to TECD, TECD is deducted from PMoney, TECD is set to zero, and PMoney is displayed. Then, flow billing routine is executed.

5.9.5 FLOW BILLING ROUTINE (Figure 5.17d1)

The flow billing routine does the followings:



No

FIGURE 5.17c2

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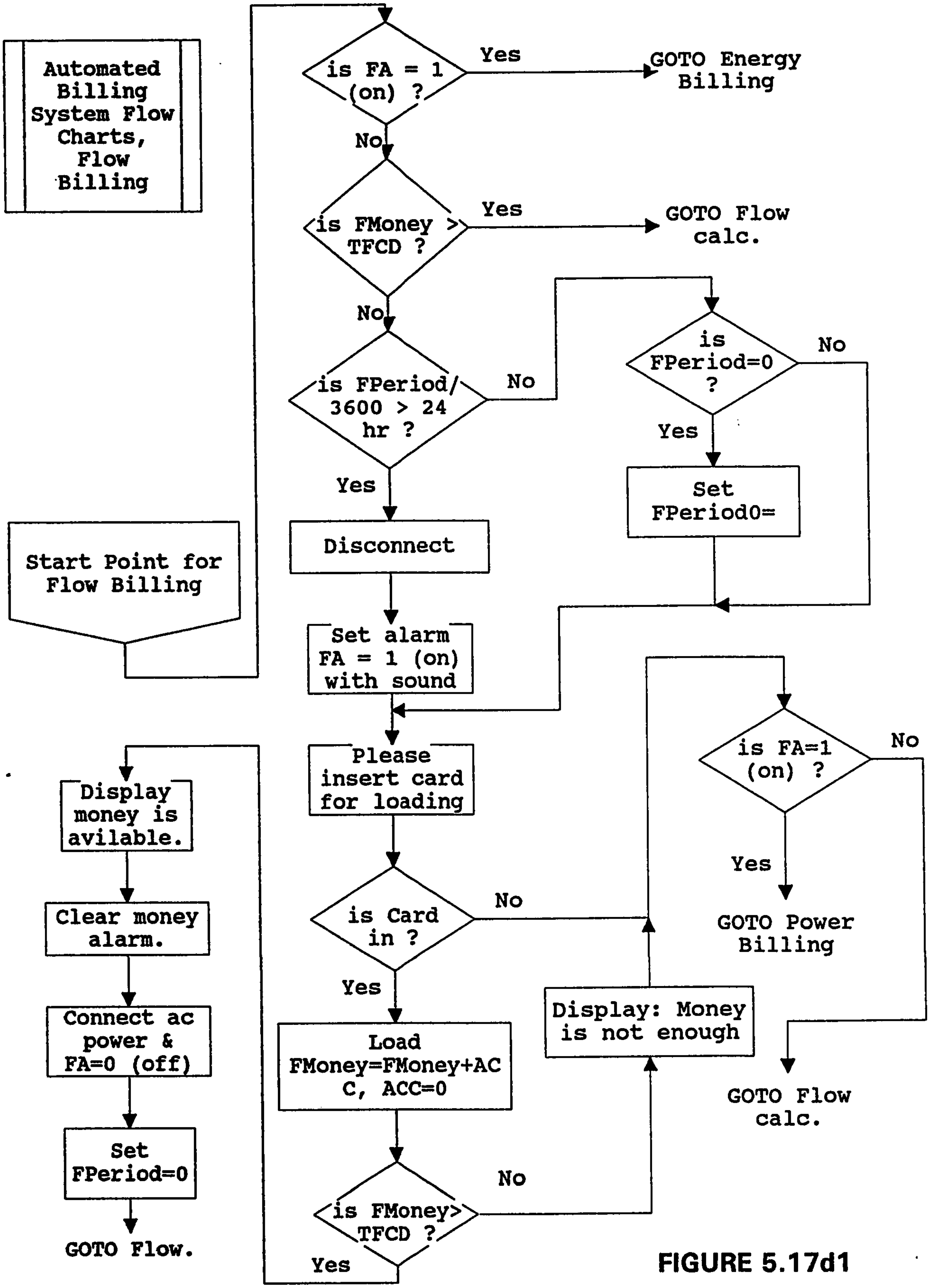

FIGURE 5.17d1

1. The flow alarm (FA) is checked. If FA is activated, the energy routine is executed. However, if not, step 2 is fetched.

2. If the credit that is available for flow (FMoney) is greater than the total flow cost to be deducted (TFCD), the flow calculation routine is executed. If not, step 3 is fetched.

3. The grace period is checked. If the flow period (FPeriod) is less than 24hr, step 4 is fetched. If not, the water/gas is disconnected, FA is set to one, and card insertion is prompted. Then, step 5 is fetched.

4. If FPeriod is equal to zero, the initial FPeriod (FPeriod0) is set to the current time and card insertion is prompted. If not, card insertion is prompted.

5. If a card is inserted, the credit amount is loaded, FMoney is incremented by ACC, ACC is set to zero, and step 7 is executed.

6. If a card is not inserted and if PA is set, the flow routine is executed. If FA is set to zero, the flow calculation routine is executed.

7. If FMoney is greater than or equal to TFCD, credit availability is displayed, credit alarm is cleared, water/gas is connected, FA and FPeriod are set to zero, and flow calculation routine is executed.

8. If FMoney is less than TFCD, low credit is displayed, FA is set to one, and step 6 is fetched.

5.9.6 **FLOW CALCULATION ROUTINE (Figure 5.17d2)**

The flow calculation routine does the followings:

1. The water/gas flow is measured. The average flow is calculated for a period of time (T).

2. Flow (F) and the total flow (TF) are calculated and displayed.

3. FTO is initialized with the current time. The total flow cost (TFC) and TFCD are calculated.

4. If FMoney is less than TFCD, the FPeriod is set to current timer minus FPeriod0, FMoney is deducted from TFCD, and TFCD is displayed. Then, energy billing routine is executed.

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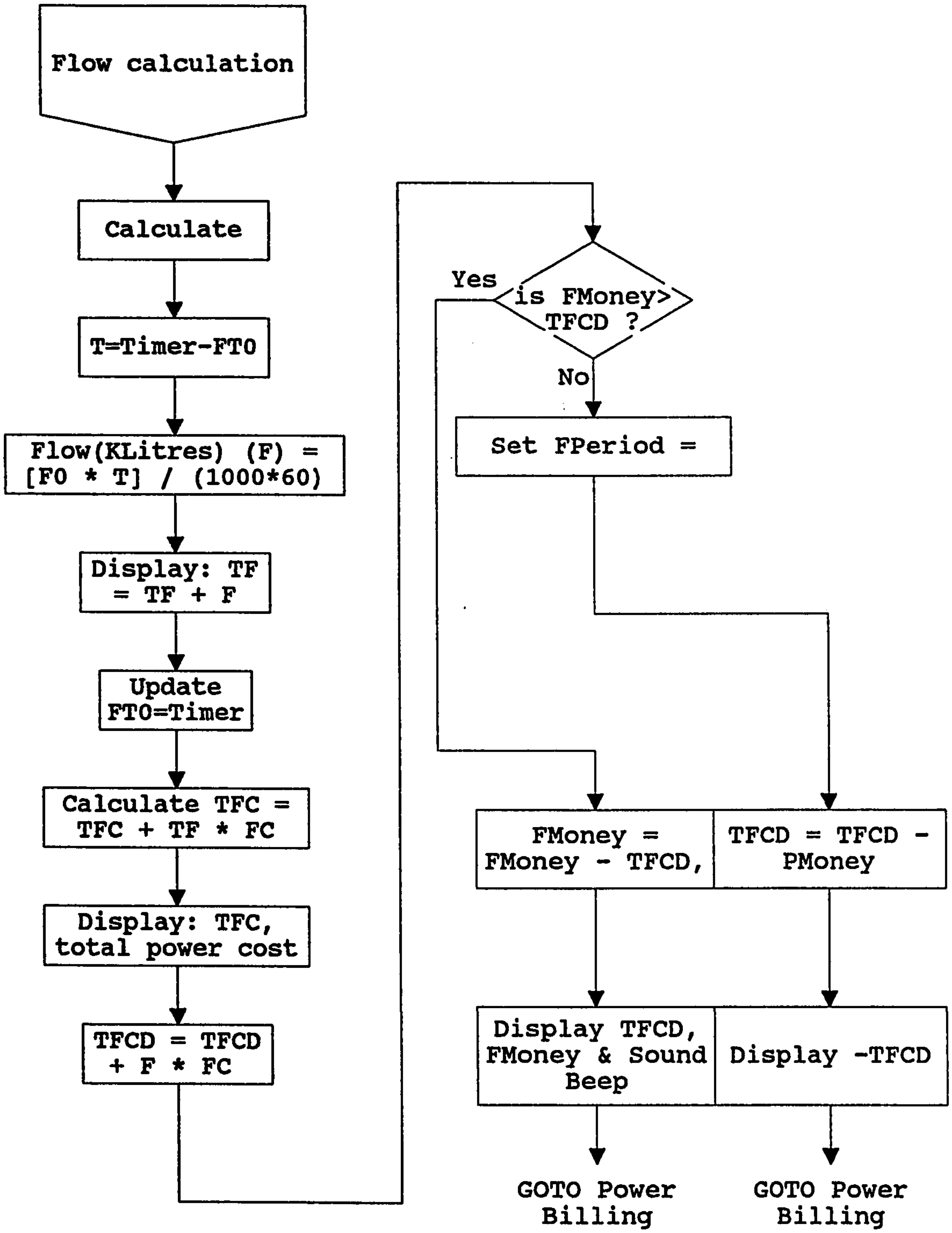

No

FIGURE 5.17d2

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5. If FMoney is greater or equal to TFCD, TFCD is deducted from FMoney, TFCD is set to zero, and FMoney is displayed. Then, energy billing routine is executed.

5.9.7 TELEPHONE CALL BILLING ROUTINE (Figure 5.17e1)

The telephone call billing routine does the followings:

1. The telephone alarm (TA) is checked. If TA is activated, a return command is executed. However, if not, step 2 is fetched.

2. If the credit that is available for telephone calls (TMoney) is greater than the total telephone calls cost to be deducted (TTC), the telephone call calculation routine is executed. If not, step 3 is fetched.

3. The grace period is checked. If the telephone period (TPeriod) is less than 24hr, step 4 is fetched. If not, the telephone line is disconnected, TA is set to one, and card insertion is prompted. Then, step 5 is fetched.

4. If TPeriod is equal to zero, the initial TPeriod (TPeriod0) is set to the current time and card insertion is prompted. If not, card insertion is prompted.

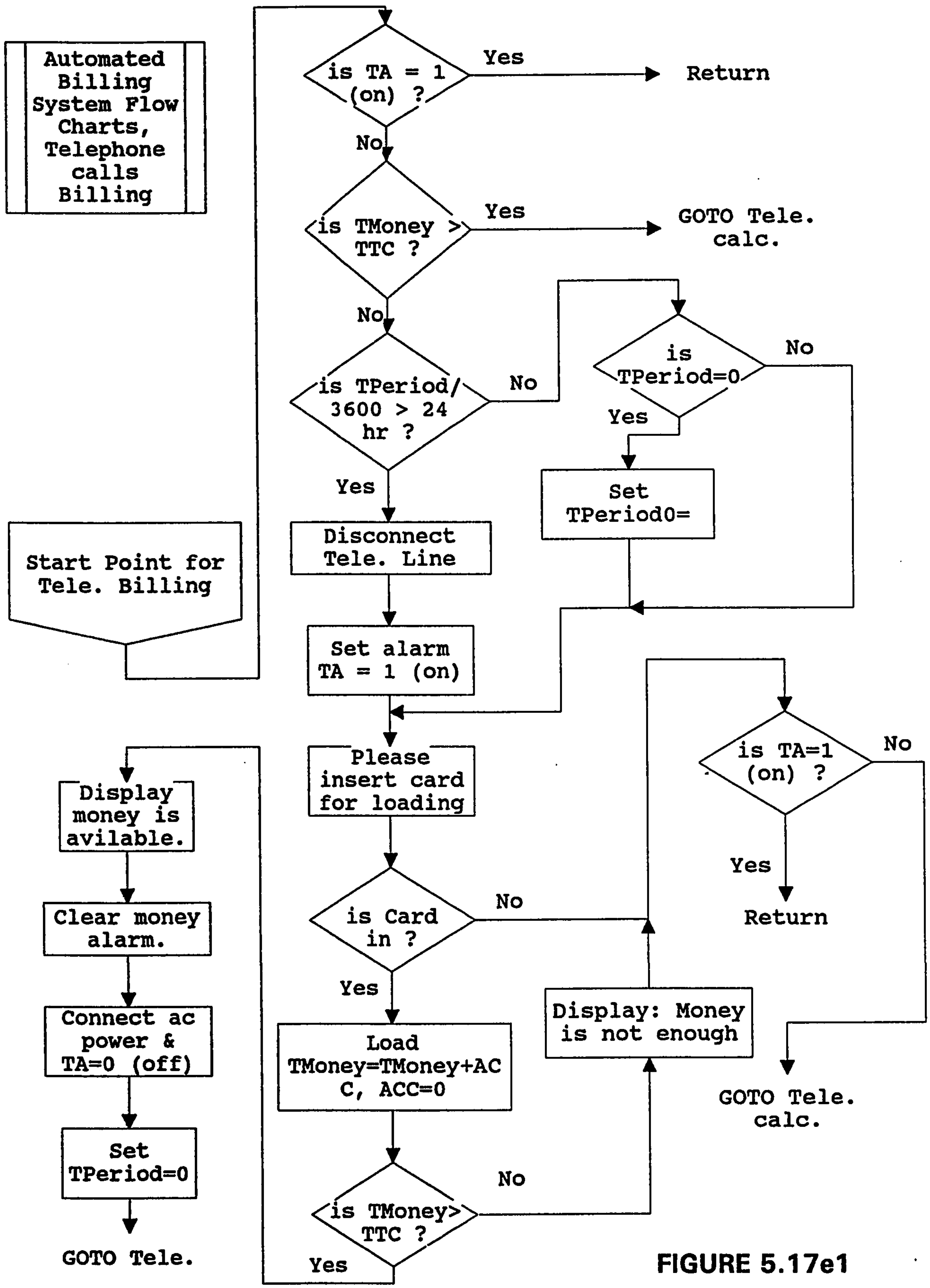

FIGURE 5.17e1

5. If a card is inserted, the credit amount is loaded, TMoney is incremented by ACC, ACC is set to zero, and step 7 is executed.

6. If a card is not inserted and if TA is set to one, the telephone call calculation routine is executed. If TA is set to zero, a return command is executed.

7. If TMoney is greater than or equal to TTC, credit availability is displayed, credit alarm is cleared, telephone line is connected, TA and FPeriod are set to zero, and telephone call routine is executed.

8. If TMoney is less than TTC, low credit is displayed, TA is set to one, and step 6 is fetched.

5.9.8 TELEPHONE CALL CALCULATION ROUTINE (Figure 5.17e2)

The telephone call billing routine does the followings:

1. If the telephone is on-hook and the code is correct (CR) is set to one, the number of dialing (I) and CR are set to zero. Then, step 11 is fetched.

2. If CR is set to zero, a return command is executed.

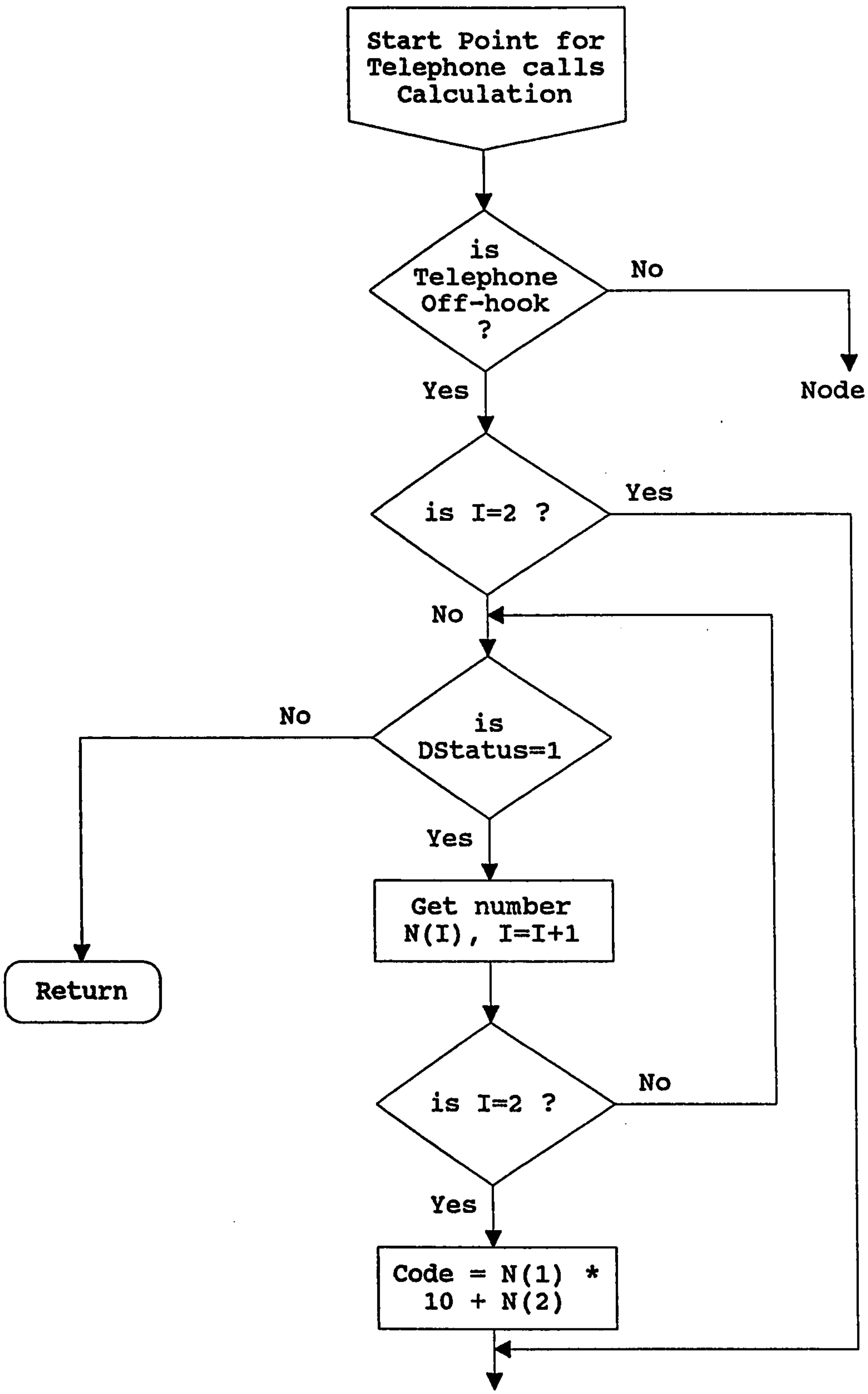

FIGURE 5.17e2

See next page

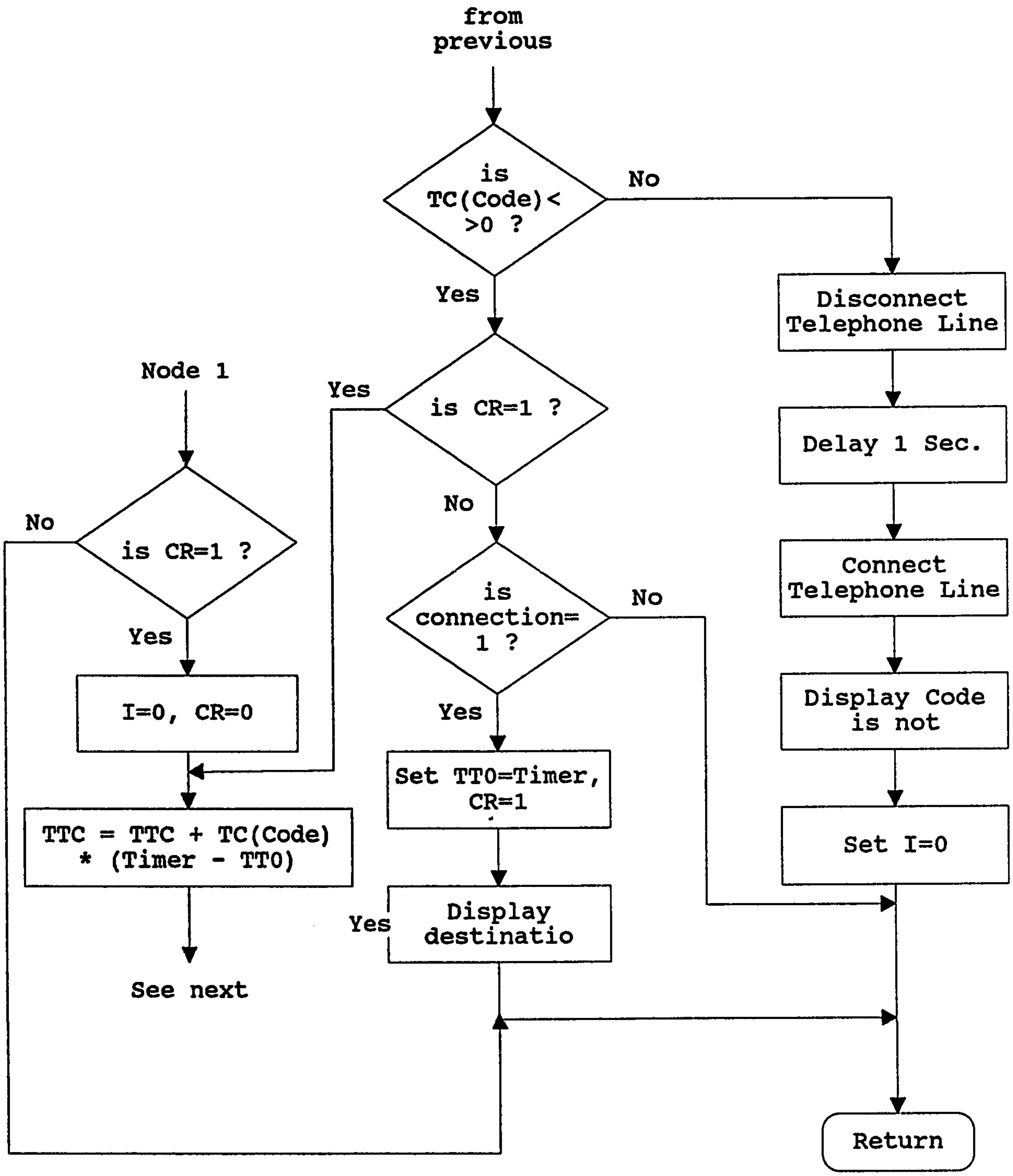

FIGURE 5.17e3

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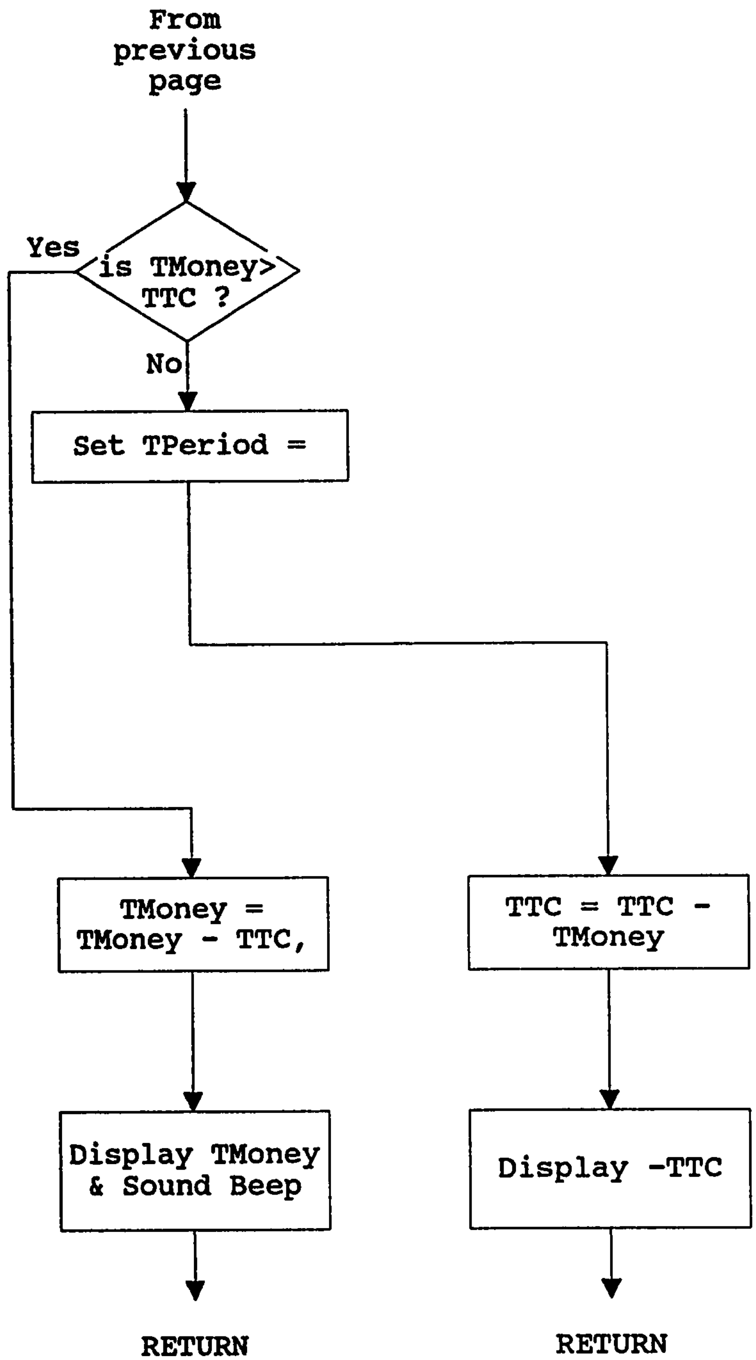

FIGURE 5.17e4

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3. If the telephone is off-hook and if I is not equal to two, step 4 is fetched.

4. If dialing status (DStatus) is not set to one, a return command is executed.

5. If DStatus is set to one, the number N(I) is deducted and I is incremented by one.

6. If I is not equal to two, a loop is fetched from step 4.

7. If I is equal to two, the code is calculated.

8. If the telephone charge for the associated code TC(code) is equal to zero, the telephone line is disconnected for one second, a code error is displayed, I is set to zero, and a return command is executed.

9. If TC(code) is not equal to zero, CR is equal to zero, and connection acknowledgment is received, the initial time TT0 is set to the current time, CR is set to one, the destination area is displayed, and a return command is executed.

10. If CR is set to one, step 11 is fetched.

11. The total telephone cost (TTC) is calculated.

12. If TMoney is less than TTC, the TPeriod is set to current timer minus TPeriod0, TMoney is deducted from TTC, TTC is displayed, and a return command is executed.

13. If TMoney is greater or equal to TTC, TTC is deducted from TMoney, TTC is set to zero, TMoney is displayed, and a return command is executed.

5.10 CIRCUITS ERROR ANALYSIS AND TEST RESULTS

As shown in Table 5.3, measurement errors may be classified as digital errors; instrumentation errors; and channel and reference failures [35]. In this section, error sources and test results for each circuit are presented.

5.10.1 ENERGY METER CIRCUIT

This circuit uses a 12-bit A/D bibolar converter for the voltage and current measurement. Therefore, the resolution ΔL is given by

Class of error	Measurement error	Characteristics
Digital errors	Digital resolution	of the form 2^{-b}
	Beyond range of digital coding	Truncation at maximum (minimum) value
Instrument errors	Miscalibration	Bias in data
	Instrument nonlinearity	Nonlinear bias in data
	Beyond dynamic range of transducer, saturation	Truncation at maximum (minimum) value
	Transducer does not measure the desired physical parameter	Bias in data, possible nonlinear
	Transducer failure	Data channel dead
Channel and reference failures	Data channel failure	Data channel dead
	Reverse wiring	sign error in data
	Common mode error	Raised ground voltage due to current in the ground wire rather than the neutral wire. Bias in data

Table 5.3, Types of Measurement Error

$$\Delta L = \frac{2F}{2^{12}} = 2^{-11}F$$

where F is the full scale of the circuit ($+F$ or $-F$). The maximum error due to truncation is $\pm 2^{-12}F$. For the voltage measurement, the error is $\pm 2^{-12} \times 10 \times 74.835 = \pm 0.18V$. For the current measurement, the error is $\pm 2^{-12} \times 10 = \pm 2.44mA$. If harmonics occur on the electric source due the loads, noise is generated that affects the circuit operation. Consequently, the VT, CT, and the electric source must be shielded and grounded to eliminate this noise. Also, the maximum power consumption by the series resistor on the electric source is given by

$$P = I^2_{load,max} R = 10^2 \times 0.1 = 10W$$

As a result, The power measured has an error that is given by

$$P_{error} = \left(\pm 2^{-12} \times 10 \times 74.835 = \pm 0.18V\right) \times \left(\pm 2^{-12} \times 10 = \pm 2.44mA\right) + 10 \;\; Watt$$

The zero-crossing technique is independent of the sampling period as long as the samples are taken within *m* number of cycles. The chosen number of cycles depend on how frequent the load is changing. The number of cycles has been chosen to be 100, which is equal to 1.67 Sec. This means every 1.65, a sample is taken.

The test results of voltage, current, power factor angle, and energy measurements for different loads are tabulated in Table 5.4, 5, 6 & 7.

Voltage (RMS, V)

Load	Measured by Oscilloscope	Measured by Propsed System	Error%
Lamp 1	128.06	127.80	0.20
Lamp 2	128.06	127.80	0.20
Pump	128.06	127.80	0.20
Saw machine	128.06	127.80	0.20

Table 5.4

Current (RMS, A)

Load	Measured by Oscilloscope	Measured by Propsed System	Error%
Lamp 1	0.39	0.40	2.56
Lamp 2	0.78	0.79	1.28
Pump	0.85	0.90	5.88
Saw machine	1.27	1.30	2.36

Table 5.5

Power factor angle (degree)

Load	Measured by Oscilloscope	Measured by Propsed System	Error%
Lamp 1	0.00	1.50	0.03
Lamp 2	0.00	1.70	0.04
Pump	12.50	12.30	1.60
Saw machine	5.50	5.30	3.63

Table 5.6

Power (Watt)

Load	Calculated from Tables 5.4,5&6	Measured by Propsed System	Error%
Lamp 1	49.80	51.12	2.65
Lamp 2	99.61	100.96	1.35
Pump	106.27	112.34	5.71
Saw machine	158.78	162.33	2.24

Table 5.7

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5.10.2 WATER/GAS FLOW METER CIRCUIT

As mentioned above, the circuit utilizes an optical turbine flow meter which has a linearity error of ±1.0% at full scale deflection (FSD). Also, the frequency to voltage converter circuit has an error of ±0.1% at full scale. The frequency of the turbine flow meter at full scale is equal to $500Hz$. Then, the maximum voltage out of F/V converter is given by

$$V_{out} = 2 \times f_{in} \times 5 \times 39pF \times 9.6M\Omega$$
$$f_{in,max} = 500Hz$$
$$\Rightarrow V_{out,max} = 1.872V$$

The volume flow rate is given by

$$Q = \frac{f}{76.92} litre/\min \tag{5.4}$$

The maximum error due to ADC truncation is $\pm 10 \times 2^{-12} = \pm 2.44mV$. Therefore, the total errors equal to the turbine error plus the F/V error and the ADC truncation error.

The flow meter circuit is affected by the power supply fluctuation. Therefore, the circuit power supply should be regulated.

The sampling period has been chosen to be 2 Sec., because of the slow change in the flow.

The test results for different flow rates are tabulated in Table 5.7.

Measured using Oscilloscope

#	V_{out}, F/V Converter (V)	Turbine Frequency (Hz)	Flow Q Calculated Lit/min	Flow Q Measured by proposed system Lit/min	Error%
1	1.20	333.33	4.33	4.20	3.00
2	0.85	238.10	3.09	3.10	0.32
3	1.00	285.71	3.71	3.60	2.96
4	0.62	166.67	2.17	2.10	3.23

Table 5.8

5.10.3 TELEPHONE CALL METER CIRCUIT

The telephone line is isolated from the digital ground using a 1:1 isolation transformer. Also, an opto-isolator is used for the off/on hook detector circuit to provide grounding isolation.

The off/on hook circuit has been designed to consume very low current, so that does not load the customer local loop and cause an off hook error.

This circuit has proven a reliability for measuring telephone call period.

5.10.4 CARD READER CIRCUIT

The most effective method to transfer data from the magnetic card to the computer is serial transfer. The transfer speed depends on the pulses speed that can be generated by the ouput port. Therfore, If the pulses are generated with a speed of X pulse/Sec., then the data transfer speed will be X unit/Sec.

5.10.5 SYSTEM REAL TIME OPERATION AND TEST RESULTS

The integrated system has been tested for 24-Hours and the system has proven to be stable within its accuracy. The commutative results for the system are tabulated in Table 5.9.

Meter	Measured by Oscilloscope & Calculated	Measured by Propsed System	Error%
Energy	$1.20kWh$	$1.25kWh$	4.17
Flow	$3.12k-gallon$	$3.31k-gallon$	6.09

Table 5.9

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SUMMARY

In this chapter, an evaluation prototype system is designed, built, and tested. It was noticed that it is feasible to integrate the different utilities in one system. Then, the system performance is evaluated on different loads. In all cases, the error sources and measurement errors have been determined. In general, the system has proven to be stable, reliable and easy to maintain within its accuracy.

CHAPTER 6

CONCLUSIONS AND SUGGESTIONS FOR FURTHER STUDIES

In this chapter, the contributions of this thesis are stated, followed by suggestions for possible future work extension.

6.1 CONCLUSIONS

A new automated billing system for public utilities (Electricity, Water/gas, and Telephone) is designed, built and tested. It is proposed to replace the existing traditional discrete systems with an integrated system. The new system provides the flexibility and reliability for customers to pay any time using a credit card. Also, the system reduces significantly the overall utility network operation costs. It uses a digital watthourmeter for energy consumption metering and a digital flow meter for water/gas metering. Further, two techniques are proposed for the digital watthourmeter implementation. Also, two methods are proposed for telephone calls metering. A prototype system is designed, built, and evaluated under different loads. The following are the main thesis results and contributions:

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1. From hardware point of view, it is feasible to integrate the three utilities (Electricity, Water/gas, and Telephone) in one system for billing using a single-chip microcontroller.

2. The system error sources are minimal due to the limited number of circuitry used in the system.

3. The system has proven to be stable, reliable and easy to maintain within its accuracy.

4. The prototype system shown in Figure 5.1 can be integrated for actual implementation in a cabinet as shown in Figure 6.1. The initial estimates for the cabinet size is 50cm by 40cm.

4. A single credit card reader can be used for the three utilities.

5. The number of voltage or current cycles *m*, over which the energy is assumed to be constant, can be as large as 100 cycles for residential application.

6. The digital sampling wattmeter is applicable for measuring the electrical energy in the presence of harmonics. On the other hand, the zero-crossing wattmeter is applicable only in the absence of harmonics.

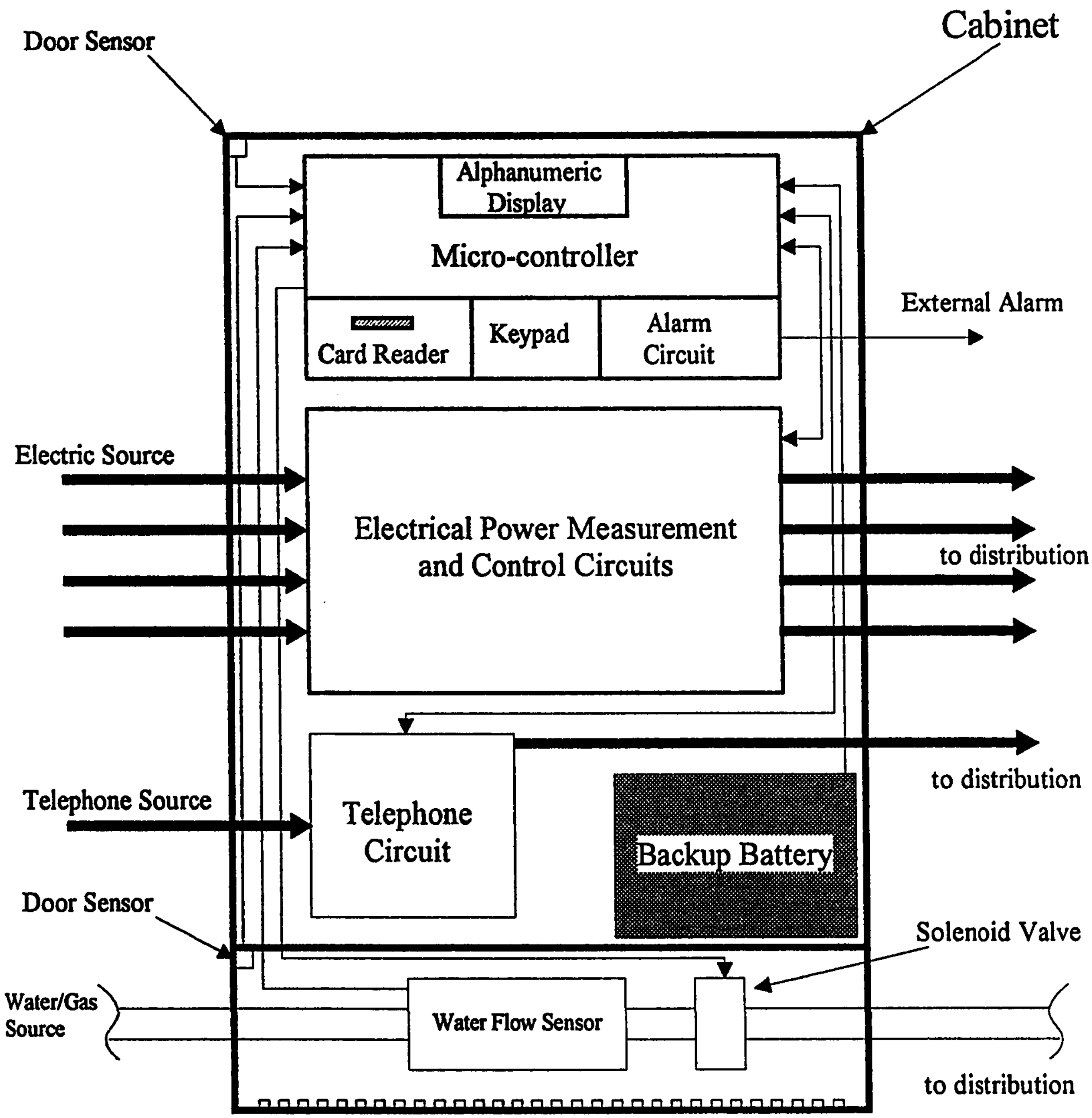

Figure 6.1, Proposed
System Layout for actual installation

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7. A magnetic or an optical flow meter can be used for water/gas metering and can be easily interfaced to a microcontroller. Also, the sampling cycle for water/gas metering can be as large as 2 Sec.

8. It is feasible to charge telephone calls using the proposed techniques (coin pulse detection & acknowledgment detection). While, the acknowledgment technique requires a data base for the city and country codes and charge rates, the coin pulse detection does not require any type of data base.

6.2 SUGGESTIONS FOR FURTHER STUDIES

The work presented in this thesis may be extended for further research in the following aspects:

1. Study the system configuration to support more than three electric feeders.

2. Study the system configuration to support more than one flow meter.

3. Study the system configuration to support more than one telephone line source.

4. Study the system configuration to support more than one customer.

5. Study and test the system operation on site.

6. Study the system integration with ISDN (Integrated Services Digital Networks) systems.

7. Investigate the coding techniques to be used in encoding the magnetic card and the system.

8. Investigate the system maintenance by the different utilities and system responsibility.

9. Remote control the system from the head office. This will be practically feasible if the system is integrated with the ISDN by utilizing the D channel which is used for signaling and data transfer.

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APPENDIX A

SIMULATION PROGRAMS FOR ELECTRICAL POWER MEASUREMENT

Method I
Digital Sampling Technique
Case I.1.1

This simulates the digital sampling technique for measuring energy.

$N := 29$ **;number of samples**

$m := 7$ **;number of cycles**

$f := 60$ **;waveform frequency**

$T := \frac{1}{f}$ **;waveform period**

$\Delta T := 4.0 \cdot 10^{-3}$ **;sampling period**

$w := 2 \cdot \pi \cdot f$

$\Phi := \frac{\pi}{6}$ $pf := \cos(\Phi)$ **;power factor angle**

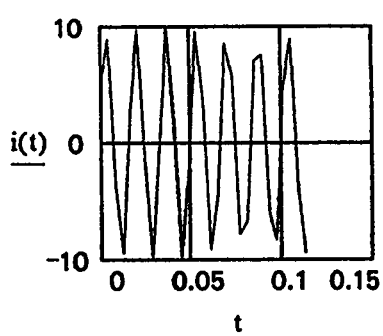
$t := 0, \Delta T .. m \cdot T - 1 \cdot 10^{-3}$

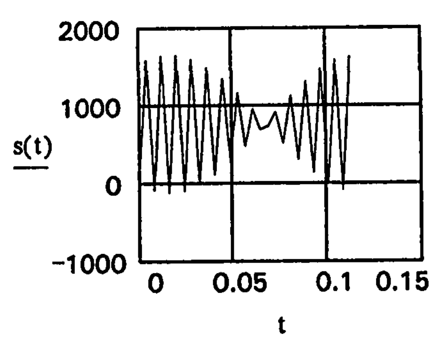
$current := 10$ $voltage := 125 \cdot \sqrt{2}$ **;amplitude values**

$i(t) := current \cdot \sin(w \cdot t + \Phi)$ **;current signal**

$v(t) := voltage \cdot \sin(w \cdot t)$ **;voltage signal**

$s(t) := v(t) \cdot i(t)$ **;volt-amp product**





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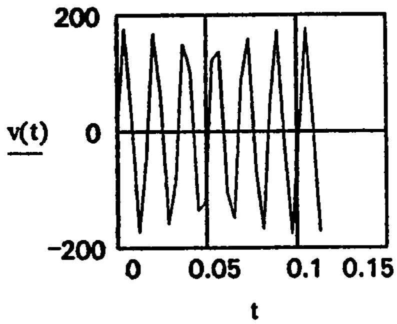


$$\mathrm{Power} := \frac{1}{N} \cdot \sum_{t} s(t)$$

$$\mathrm{Total\_Power} := \mathrm{Power}$$

$$\mathrm{Actual\_Power} := \frac{1}{m \cdot T} \cdot \int_{0}^{m \cdot T} s(t)\, dt$$

$$\mathrm{Total\_Actual\_Power} := \mathrm{Actual\_Power}$$

$$\mathrm{Error\%} := \left| \frac{\mathrm{Total\_Actual\_Power} - \mathrm{Total\_Power}}{\mathrm{Total\_Actual\_Power}} \right| \cdot 100$$

$pf = 0.86603$ $m = 7$ $N = 29$ $\mathrm{current} = 10$ $\mathrm{voltage} = 176.7767$

$\Delta T = 0.004$

$\mathrm{Total\_Actual\_Power} = 765.46555$

$\mathrm{Total\_Power} = 767.9632$

$\mathrm{Error\%} = 0.32629$

Method I
Digital Sampling Technique
Case I.1.2

This simulates the digital sampling technique for measuring energy.

$N := 29$ **;number of samples**

$m := 7$ **;number of cycles**

$f := 60$ **;waveform frequency**

$T := \frac{1}{f}$ **;waveform period**

$\Delta T := 4.02 \cdot 10^{-3}$ **;sampling period**

$w := 2 \cdot \pi \cdot f$

$\Phi := \frac{\pi}{6}$ $\quad$ $pf := \cos(\Phi)$ **;power factor angle**

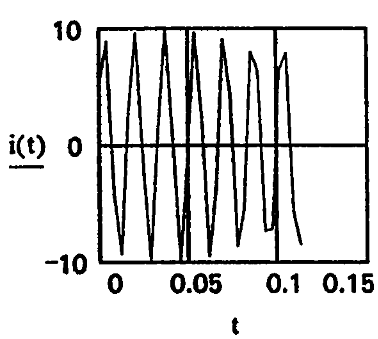
$t := 0, \Delta T .. m \cdot T - 1 \cdot 10^{-3}$

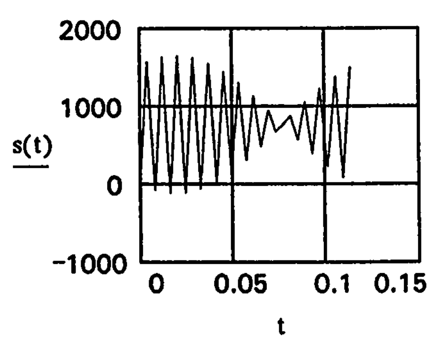
$current := 10$ $\quad$ $voltage := 125 \cdot \sqrt{2}$ **;amplitude values**

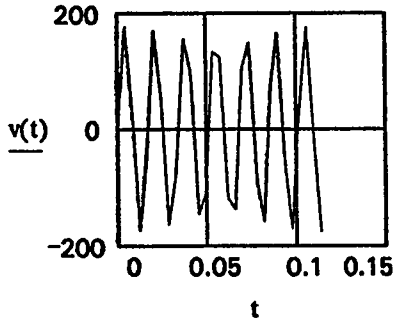
$i(t) := current \cdot \sin(w \cdot t + \Phi)$ **;current signal**

$v(t) := voltage \cdot \sin(w \cdot t)$ **;voltage signal**

$s(t) := v(t) \cdot i(t)$ **;volt-amp product**







$$Power := \frac{1}{N} \cdot \sum_{t} s(t)$$

$$Total\_Power := Power$$

$$Actual\_Power := \frac{1}{m \cdot T} \cdot \int_{0}^{m \cdot T} s(t)\, dt$$

$$Total\_Actual\_Power := Actual\_Power$$

$$Error\% := \left| \frac{Total\_Actual\_Power - Total\_Power}{Total\_Actual\_Power} \right| \cdot 100$$

$pf = 0.86603$ $m = 7$ $N = 29$ $current = 10$ $voltage = 176.7767$

$\Delta T = 0.00402$

$Total\_Actual\_Power = 765.46555$

$Total\_Power = 765.98353$

$Error\% = 0.06767$

123

Method I
Digital Sampling Technique
Case I.1.3

This simulates the digital sampling technique for measuring energy.

$N := 29$ **;number of samples**

$m := 7$ **;number of cycles**

$f := 60$ **;waveform frequency**

$T := \frac{1}{f}$ **;waveform period**

$\Delta T := 4.023 \cdot 10^{-3}$ **;sampling period**

$w := 2 \cdot \pi \cdot f$

$\Phi := \frac{\pi}{6}$ $pf := \cos(\Phi)$ **;power factor angle**

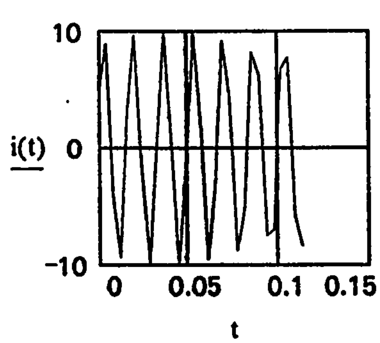
$t := 0, \Delta T .. m \cdot T - 1 \cdot 10^{-3}$

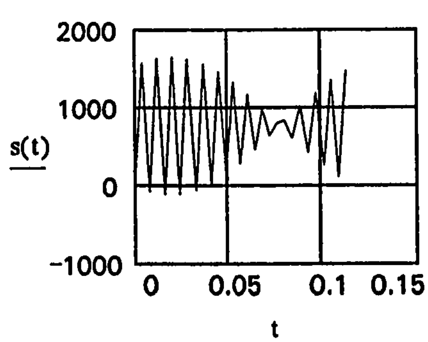
$current := 10$ $voltage := 125 \cdot \sqrt{2}$ **;amplitude values**

$i(t) := current \cdot \sin(w \cdot t + \Phi)$ **;current signal**

$v(t) := voltage \cdot \sin(w \cdot t)$ **;voltage signal**

$s(t) := v(t) \cdot i(t)$ **;volt-amp product**





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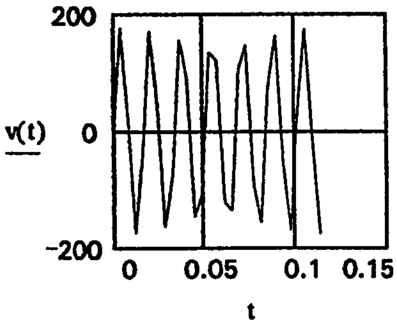


$$\text{Power} := \frac{1}{N} \cdot \sum_{t} s(t)$$

$$\text{Total\_Power} := \text{Power}$$

$$\text{Actual\_Power} := \frac{1}{m \cdot T} \cdot \int_{0}^{m \cdot T} s(t)\, dt$$

$$\text{Total\_Actual\_Power} := \text{Actual\_Power}$$

$$\text{Error\%} := \left| \frac{\text{Total\_Actual\_Power} - \text{Total\_Power}}{\text{Total\_Actual\_Power}} \right| \cdot 100$$

$pf = 0.86603$ $m = 7$ $N = 29$ $current = 10$ $voltage = 176.7767$

$\Delta T = 0.00402$

$\text{Total\_Actual\_Power} = 765.46555$

$\text{Total\_Power} = 765.46345$

$\text{Error\%} = 2.73904 \cdot 10^{-4}$

123

Method I
Digital Sampling Technique
Case I.2.1

This simulates the digital sampling technique for measuring energy.

$N := 20$;number of samples

$m := 7$;number of cycles

$f := 60$;waveform frequency

$T := \frac{1}{f}$;waveform period

$\Delta T := 5.8 \cdot 10^{-3}$;sampling period

$w := 2 \cdot \pi \cdot f$

$\Phi := \frac{\pi}{6}$ $\quad pf := \cos(\Phi)$;power factor angle

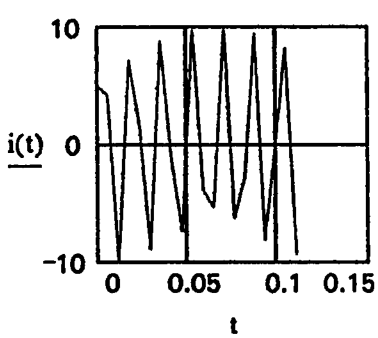
$t := 0, \Delta T .. m \cdot T - 1 \cdot 10^{-3}$

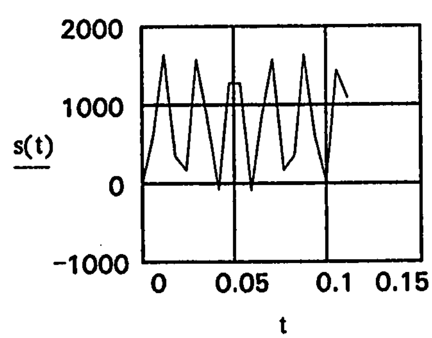
$current := 10$ $\quad voltage := 125 \cdot \sqrt{2}$;amplitude values

$i(t) := current \cdot \sin(w \cdot t + \Phi)$;current signal

$v(t) := voltage \cdot \sin(w \cdot t)$;voltage signal

$s(t) := v(t) \cdot i(t)$;volt-amp product





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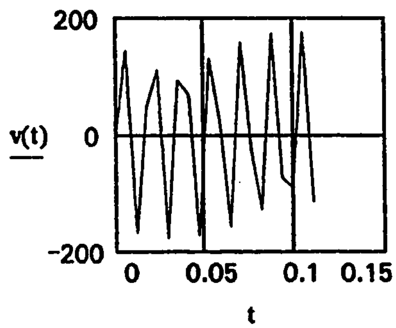


$$\mathrm{Power} := \frac{1}{N}\cdot\sum_{t} s(t)$$

$$\mathrm{Total\_Power} := \mathrm{Power}$$

$$\mathrm{Actual\_Power} := \frac{1}{m\cdot T}\cdot\int_{0}^{m\cdot T} s(t)\,dt$$

$$\mathrm{Total\_Actual\_Power} := \mathrm{Actual\_Power}$$

$$\mathrm{Error\%} := \left|\frac{\mathrm{Total\_Actual\_Power} - \mathrm{Total\_Power}}{\mathrm{Total\_Actual\_Power}}\right|\cdot 100$$

$pf = 0.86603$ $m = 7$ $N = 20$ $\mathrm{current} = 10$ $\mathrm{voltage} = 176.7767$

$\Delta T = 0.0058$

$\mathrm{Total\_Actual\_Power} = 765.46555$

$\mathrm{Total\_Power} = 760.93154$

$\mathrm{Error\%} = 0.59232$

123

Method I
Digital Sampling Technique
Case I.2.2

This simulates the digital sampling technique for measuring energy.

$N := 20$;number of samples

$m := 7$;number of cycles

$f := 60$;waveform frequency

$T := \frac{1}{f}$;waveform period

$\Delta T := 5.83 \cdot 10^{-3}$;sampling period

$w := 2 \cdot \pi \cdot f$

$\Phi := \frac{\pi}{6}$ $pf := \cos(\Phi)$;power factor angle

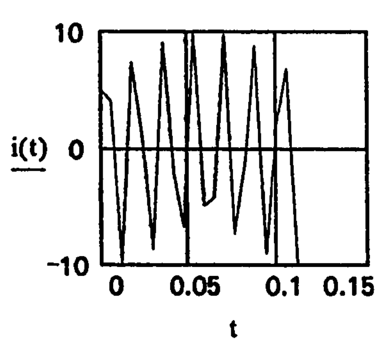
$t := 0, \Delta T .. m \cdot T - 1 \cdot 10^{-3}$

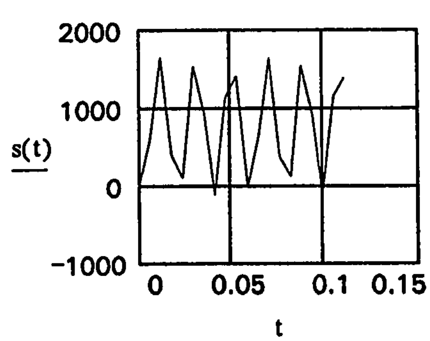
$current := 10$ $voltage := 125 \cdot \sqrt{2}$;amplitude values

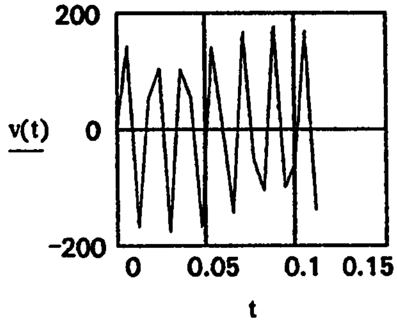
$i(t) := current \cdot \sin(w \cdot t + \Phi)$;current signal

$v(t) := voltage \cdot \sin(w \cdot t)$;voltage signal

$s(t) := v(t) \cdot i(t)$;volt-amp product







$$\text{Power} := \frac{1}{N} \cdot \sum_{t} s(t)$$

$$\text{Total\_Power} := \text{Power}$$

$$\text{Actual\_Power} := \frac{1}{m \cdot T} \cdot \int_{0}^{m \cdot T} s(t)\, dt$$

$$\text{Total\_Actual\_Power} := \text{Actual\_Power}$$

$$\text{Error\%} := \left| \frac{\text{Total\_Actual\_Power} - \text{Total\_Power}}{\text{Total\_Actual\_Power}} \right| \cdot 100$$

$pf = 0.86603$ $m = 7$ $N = 20$ $\text{current} = 10$ $\text{voltage} = 176.7767$

$\Delta T = 0.00583$

$\text{Total\_Actual\_Power} = 765.46555$

$\text{Total\_Power} = 765.28966$

$\text{Error\%} = 0.02298$

123

Method I
Digital Sampling Technique
Case I.2.3

This simulates the digital sampling technique for measuring energy.

$N := 20$ **;number of samples**

$m := 7$ **;number of cycles**

$f := 60$ **;waveform frequency**

$T := \frac{1}{f}$ **;waveform period**

$\Delta T := 5.8333 \cdot 10^{-3}$ **;sampling period**

$w := 2 \cdot \pi \cdot f$

$\Phi := \frac{\pi}{6}$ $pf := \cos(\Phi)$ **;power factor angle**

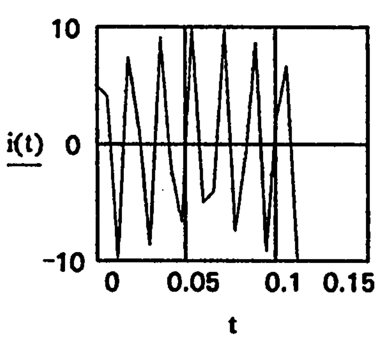
$t := 0, \Delta T .. m \cdot T - 1 \cdot 10^{-3}$

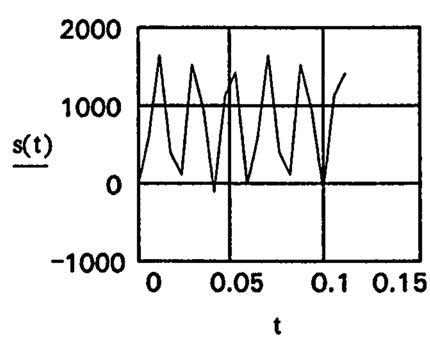
$current := 10$ $voltage := 125 \cdot \sqrt{2}$ **;amplitude values**

$i(t) := current \cdot \sin(w \cdot t + \Phi)$ **;current signal**

$v(t) := voltage \cdot \sin(w \cdot t)$ **;voltage signal**

$s(t) := v(t) \cdot i(t)$ **;volt-amp product**





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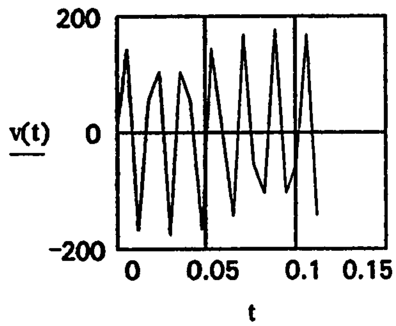


$$Power := \frac{1}{N} \cdot \sum_{t} s(t)$$

$$Total\_Power := Power$$

$$Actual\_Power := \frac{1}{m \cdot T} \cdot \int_{0}^{m \cdot T} s(t)\, dt$$

$$Total\_Actual\_Power := Actual\_Power$$

$$Error\% := \left| \frac{Total\_Actual\_Power - Total\_Power}{Total\_Actual\_Power} \right| \cdot 100$$

$pf = 0.86603$ $\quad m = 7$ $\quad N = 20$ $\quad current = 10$ $\quad voltage = 176.7767$

$\Delta T = 0.00583$

$Total\_Actual\_Power = 765.46555$

$Total\_Power = 765.46411$

$Error\% = 1.88085 \cdot 10^{-4}$

Method I
Digital Sampling Technique
Case I.2.4

This simulates the digital sampling technique for measuring energy.

$N := 4$ **;number of samples**

$m := 7$ **;number of cycles**

$f := 60$ **;waveform frequency**

$T := \frac{1}{f}$ **;waveform period**

$\Delta T := 29.0 \cdot 10^{-3}$ **;sampling period**

$w := 2 \cdot \pi \cdot f$

$\Phi := \frac{\pi}{6}$ $pf := \cos(\Phi)$ **;power factor angle**

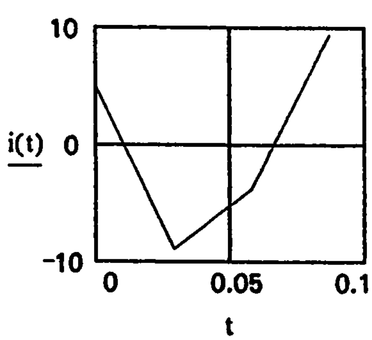
$t := 0, \Delta T .. m \cdot T - 1 \cdot 10^{-3}$

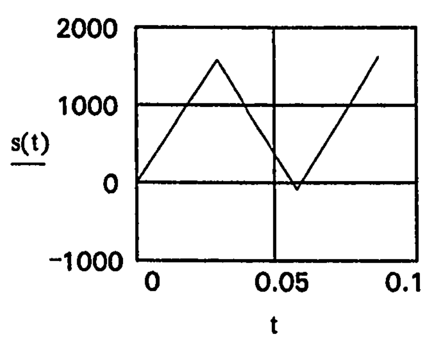
$current := 10$ $voltage := 125 \cdot \sqrt{2}$ **;amplitude values**

$i(t) := current \cdot \sin(w \cdot t + \Phi)$ **;current signal**

$v(t) := voltage \cdot \sin(w \cdot t)$ **;voltage signal**

$s(t) := v(t) \cdot i(t)$ **;volt-amp product**





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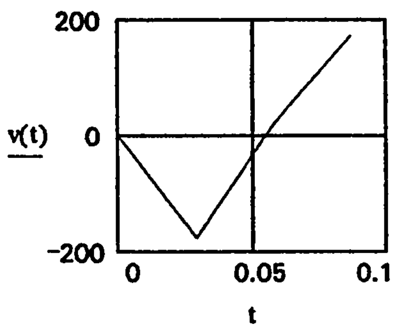


$$\text{Power} := \frac{1}{N} \cdot \sum_{t} s(t)$$

$$\text{Total\_Power} := \text{Power}$$

$$\text{Actual\_Power} := \frac{1}{m \cdot T} \cdot \int_{0}^{m \cdot T} s(t)\, dt$$

$$\text{Total\_Actual\_Power} := \text{Actual\_Power}$$

$$\text{Error\%} := \left| \frac{\text{Total\_Actual\_Power} - \text{Total\_Power}}{\text{Total\_Actual\_Power}} \right| \cdot 100$$

$pf = 0.86603$ $m = 7$ $N = 4$ $current = 10$ $voltage = 176.7767$

$\Delta T = 0.029$

Total_Actual_Power = 765.46555

Total_Power = 783.57356

Error% = 2.36562

123

Method I
Digital Sampling Technique
Case I.2.5

This simulates the digital sampling technique for measuring energy.

$N := 4$;number of samples

$m := 7$;number of cycles

$f := 60$;waveform frequency

$T := \frac{1}{f}$;waveform period

$\Delta T := 29.2 \cdot 10^{-3}$;sampling period

$w := 2 \cdot \pi \cdot f$

$\Phi := \frac{\pi}{6}$ $pf := \cos(\Phi)$;power factor angle

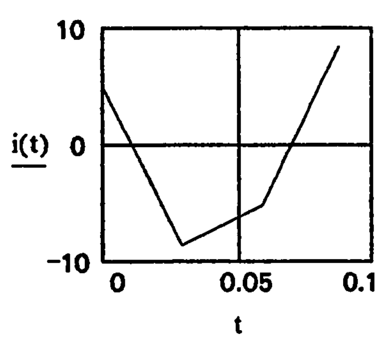
$t := 0, \Delta T .. m \cdot T - 1 \cdot 10^{-3}$

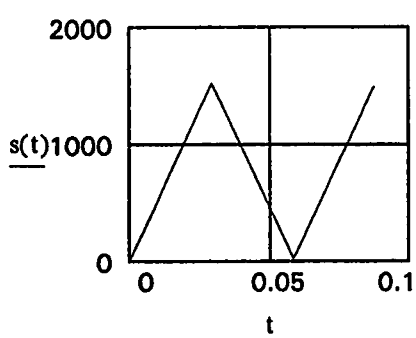
$current := 10$ $voltage := 125 \cdot \sqrt{2}$;amplitude values

$i(t) := current \cdot \sin(w \cdot t + \Phi)$;current signal

$v(t) := voltage \cdot \sin(w \cdot t)$;voltage signal

$s(t) := v(t) \cdot i(t)$;volt-amp product





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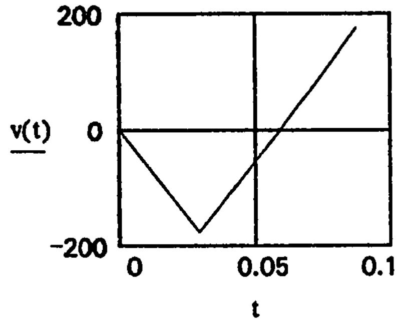


$$\mathrm{Power} := \frac{1}{N} \cdot \sum_{t} s(t)$$

$$\mathrm{Total\_Power} := \mathrm{Power}$$

$$\mathrm{Actual\_Power} := \frac{1}{m \cdot T} \cdot \int_{0}^{m \cdot T} s(t)\, dt$$

$$\mathrm{Total\_Actual\_Power} := \mathrm{Actual\_Power}$$

$$\mathrm{Error\%} := \left| \frac{\mathrm{Total\_Actual\_Power} - \mathrm{Total\_Power}}{\mathrm{Total\_Actual\_Power}} \right| \cdot 100$$

$pf = 0.86603$ $m = 7$ $N = 4$ $\mathrm{current} = 10$ $\mathrm{voltage} = 176.7767$

$\Delta T = 0.0292$

$\mathrm{Total\_Actual\_Power} = 765.46555$

$\mathrm{Total\_Power} = 759.55536$

$\mathrm{Error\%} = 0.7721$

Method I
Digital Sampling Technique
Case I.2.6

This simulates the digital sampling technique for measuring energy.

$N := 4$ **;number of samples**

$m := 7$ **;number of cycles**

$f := 60$ **;waveform frequency**

$T := \frac{1}{f}$ **;waveform period**

$\Delta T := 29.1667 \cdot 10^{-3}$ **;sampling period**

$w := 2 \cdot \pi \cdot f$

$\Phi := \frac{\pi}{6}$ $pf := \cos(\Phi)$ **;power factor angle**

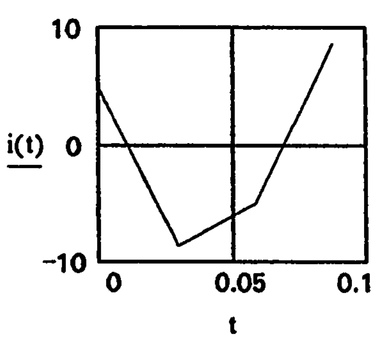
$t := 0, \Delta T .. m \cdot T - 1 \cdot 10^{-3}$

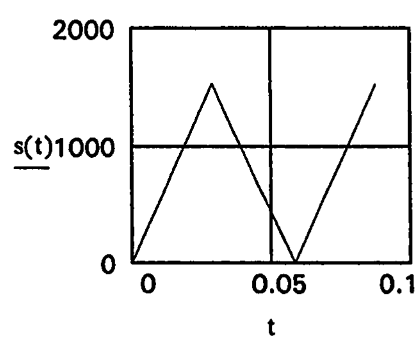
$current := 10$ $voltage := 125 \cdot \sqrt{2}$ **;amplitude values**

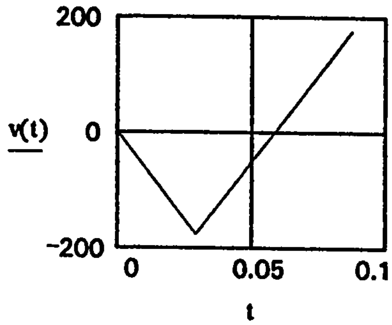
$i(t) := current \cdot \sin(w \cdot t + \Phi)$ **;current signal**

$v(t) := voltage \cdot \sin(w \cdot t)$ **;voltage signal**

$s(t) := v(t) \cdot i(t)$ **;volt-amp product**







$$\text{Power} := \frac{1}{N}\cdot\sum_{t} s(t)$$

$$\text{Total\_Power} := \text{Power}$$

$$\text{Actual\_Power} := \frac{1}{m\cdot T}\cdot\int_{0}^{m\cdot T} s(t)\,dt$$

$$\text{Total\_Actual\_Power} := \text{Actual\_Power}$$

$$\text{Error\%} := \left|\frac{\text{Total\_Actual\_Power} - \text{Total\_Power}}{\text{Total\_Actual\_Power}}\right|\cdot 100$$

$pf = 0.86603$ $m = 7$ $N = 4$ $current = 10$ $voltage = 176.7767$

$\Delta T = 0.02917$

Total_Actual_Power = 765.46555

Total_Power = 765.45999

$\text{Error\%} = 7.25747\cdot 10^{-4}$

123

Method I
Digital Sampling Technique
Case I.3.1

This simulates the digital sampling technique for measuring energy.

$N := 29$ **;number of samples**

$m := 7$ **;number of cycles**

$f := 60$ **;waveform frequency**

$T := \frac{1}{f}$ **;waveform period**

$\Delta T := 4.023 \cdot 10^{-3}$ **;samling period**

$Delay := 100 \cdot 10^{-6}$

$w := 2 \cdot \pi \cdot f$

$\Phi := \frac{\pi}{6}$ $pf := \cos(\Phi)$ **;power factor angle**

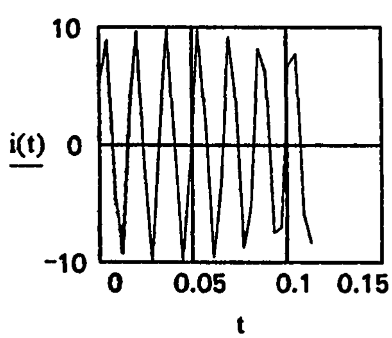
$t := 0, \Delta T .. m \cdot T - 1 \cdot 10^{-3}$

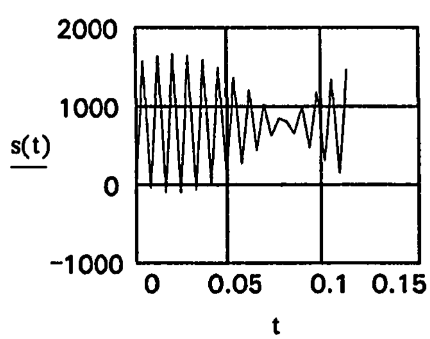
$current := 10$ $voltage := 125 \cdot \sqrt{2}$ **;amplitude values**

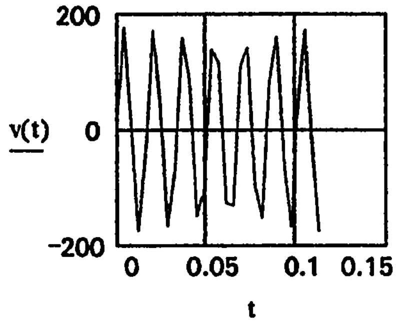
$i(t) := current \cdot \sin(w \cdot t + \Phi)$ **;current signal**

$v(t) := voltage \cdot \sin(w \cdot (t + Delay))$ **;voltage signal**

$s(t) := v(t) \cdot i(t)$ **;volt-amp product**







$$\text{Power} := \frac{1}{N} \cdot \sum_{t} s(t)$$

$$\text{Total\_Power} := \text{Power}$$

$$v(t) := \text{voltage} \cdot \sin(w \cdot t)$$

$$s(t) := v(t) \cdot i(t)$$

$$\text{Actual\_Power} := \frac{1}{T} \cdot \int_{0}^{T} s(t)\, dt$$

$$\text{Total\_Actual\_Power} := \text{Actual\_Power}$$

$$\text{Error\%} := \left| \frac{\text{Total\_Actual\_Power} - \text{Total\_Power}}{\text{Total\_Actual\_Power}} \right| \cdot 100$$

$pf = 0.8660254$ $m = 7$ $N = 29$ $\text{current} = 10$ $\text{voltage} = 176.7766953$

$\Delta T = 0.004023$

$\text{Total\_Actual\_Power} = 765.465546$

$\text{Total\_Power} = 781.5763104$

$\text{Error\%} = 2.1047014$

Method I
Digital Sampling Technique
Case II.1

This simulates the digital sampling technique for measuring energy.

$N := 29$ **;number of samples**

$m := 1$ **;number of samples**

$f := 60$ **;waveform frequency** $T := \frac{1}{f}$ **;waveform period**

$V := 125 \cdot \sqrt{2}$ **;amplitude values**

$w := 2 \cdot \pi \cdot f$

$I1 := 1 \cdot 10$ $the1 := \frac{\pi}{6}$ $I5 := \frac{I1}{5}$ $the5 := \frac{\pi}{12}$ $I7 := \frac{I1}{7}$ $the7 := \frac{\pi}{6}$

$I11 := \frac{I1}{11}$ $the11 := \frac{\pi}{12}$ **;constructing the current harmonics**

$t := 0, 0.167 \cdot 10^{-3} .. m \cdot T$ **;this is for graphing the signals**

$v(t) := V \cdot \sin(w \cdot t)$ **;voltage signal** **;volt-amp product**

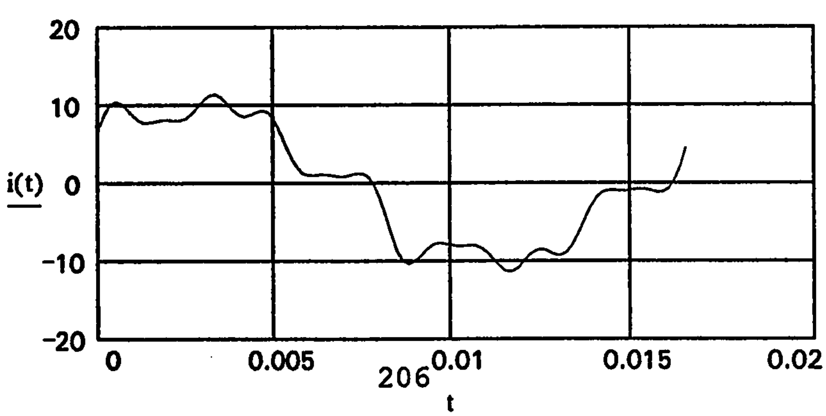
$i(t) := I1 \cdot \sin(w \cdot t + the1) + I5 \cdot \sin(w \cdot t \cdot 5 + the5) + I7 \cdot \sin(w \cdot t \cdot 7 + the7) + I11 \cdot \sin(w \cdot t \cdot 11 + the11)$

;current signal

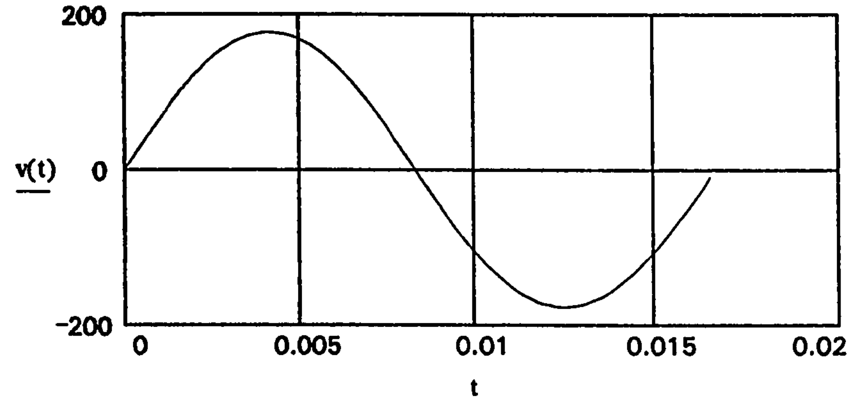
$s(t) := v(t) \cdot i(t)$

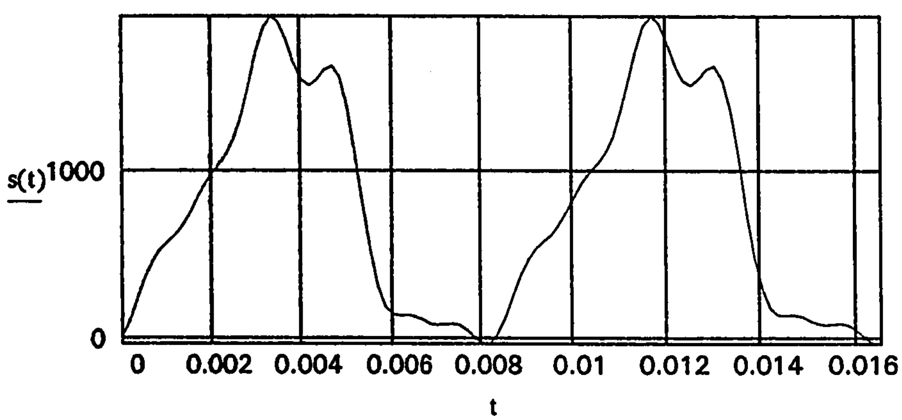
$$Actual\_Power := \frac{1}{m \cdot T} \cdot \int_0^{m \cdot T} s(t)\, dt$$

$Actual\_Power = 765.46554$



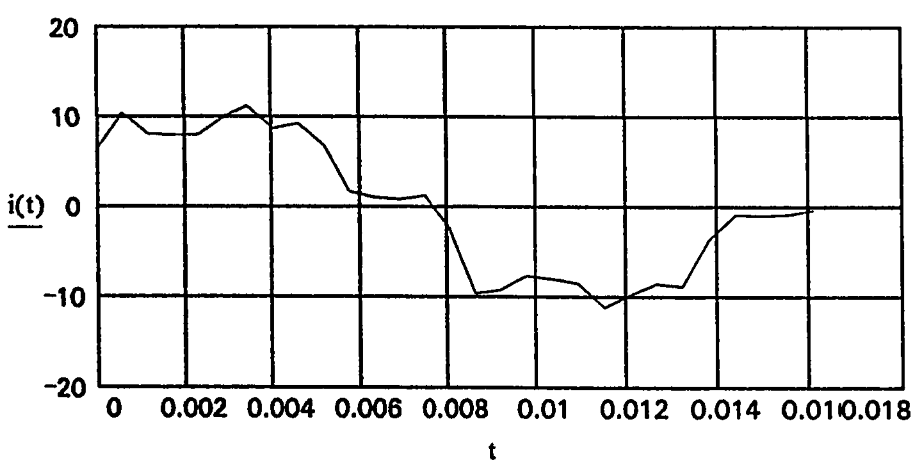
123





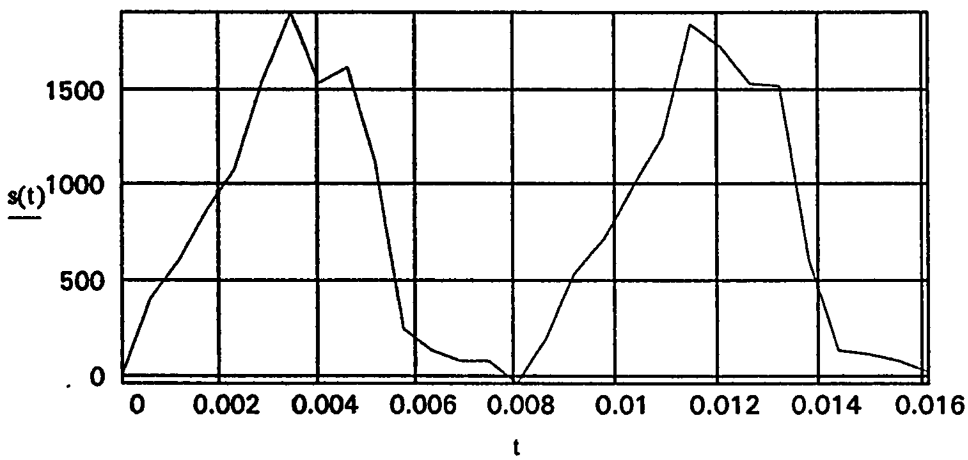
$\Delta T := \frac{m \cdot T}{N}$;sampling period

$t := 0, \Delta T .. m \cdot T - 0.1 \cdot 10^{-3}$



123

$s(t) := v(t) \cdot i(t)$



$$Power := \frac{1}{N} \cdot \sum_{t} s(t)$$

$Power = 765.46554$

$$Error\% := \left| \frac{Actual\_Power - Power}{Actual\_Power} \right| \cdot 100$$

$Error\% = 2.79078 \cdot 10^{-8}$

123

Method I
Digital Sampling Technique
Case II.2

This simulates the digital sampling technique for measuring energy.

$N := 12$ **;number of samples**

$m := 1$ **;number of samples**

$f := 60$ **;waveform frequency** $T := \frac{1}{f}$ **;waveform period**

$V := 125\cdot\sqrt{2}$ **;amplitude values**

$w := 2\cdot\pi\cdot f$

$I1 := 1\cdot 10$ $the1 := \frac{\pi}{6}$ $I5 := \frac{I1}{5}$ $the5 := \frac{\pi}{12}$ $I7 := \frac{I1}{7}$ $the7 := \frac{\pi}{6}$

$I11 := \frac{I1}{11}$ $the11 := \frac{\pi}{12}$ **;constructing the current harmonics**

$t := 0, 0.167\cdot 10^{-3} .. m\cdot T$ **;this is for graphing the signals**

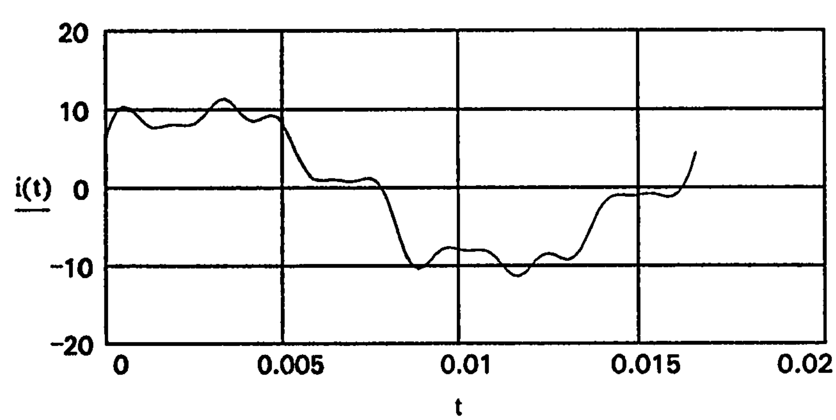
$v(t) := V\cdot \sin(w\cdot t)$ **;voltage signal** **;volt-amp product**

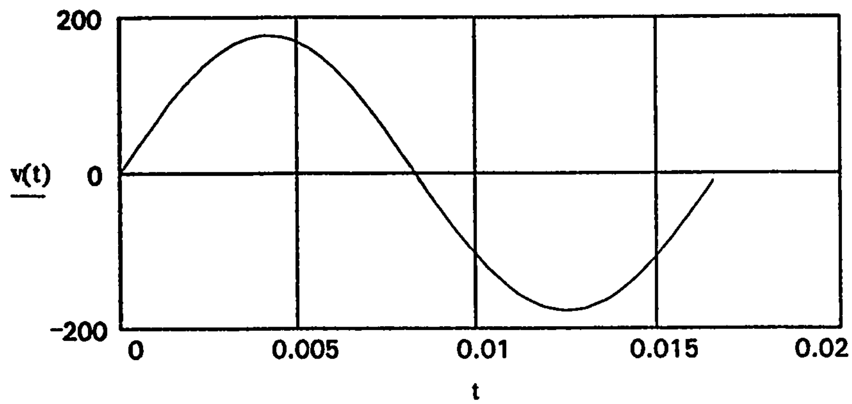
$i(t) := I1\cdot \sin(w\cdot t + the1) + I5\cdot \sin(w\cdot t\cdot 5 + the5) + I7\cdot \sin(w\cdot t\cdot 7 + the7) + I11\cdot \sin(w\cdot t\cdot 11 + the11)$

;current signal

$$Actual\_Power := \frac{1}{T}\cdot\int_0^T (v(t)\cdot i(t))\, dt$$

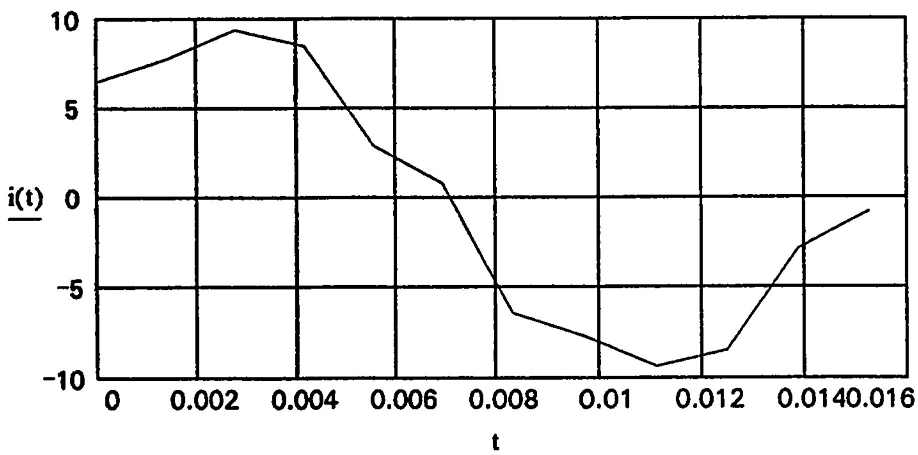
$Actual\_Power = 765.46554$



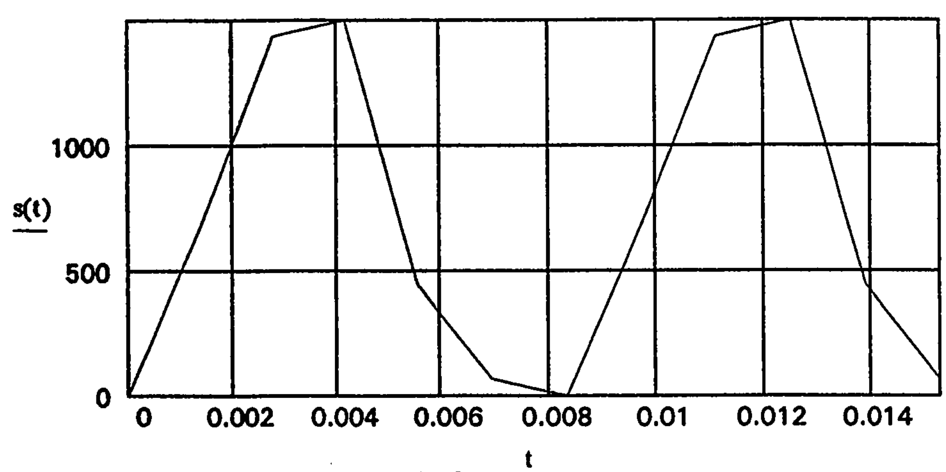


$$\Delta T := \frac{m \cdot T}{N}$$ **;sampling period**

$t := 0, \Delta T .. m \cdot T - .5 \cdot 10^{-3}$



$s(t) := v(t) \cdot i(t)$



123

$$\text{Power} := \frac{1}{N} \cdot \sum_{t} s(t)$$

Power = 687.85046

$$\text{Error\%} := \left| \frac{\text{Actual\_Power} - \text{Power}}{\text{Actual\_Power}} \right| \cdot 100$$

Error% = 10.13959

Method I
Digital Sampling Technique
Case II.3

This simulates the digital sampling technique for measuring energy.

$N := 3$ **;number of samples**

$m := 1$ **;number of samples**

$f := 60$ **;waveform frequency** $T := \frac{1}{f}$ **;waveform period**

$V := 125\cdot\sqrt{2}$ **;amplitude values**

$w := 2\cdot\pi\cdot f$

$I1 := 1\cdot 10$ $the1 := \frac{\pi}{6}$ $I5 := \frac{I1}{5}$ $the5 := \frac{\pi}{12}$ $I7 := \frac{I1}{7}$ $the7 := \frac{\pi}{6}$

$I11 := \frac{I1}{11}$ $the11 := \frac{\pi}{12}$ **;constructing the current harmonics**

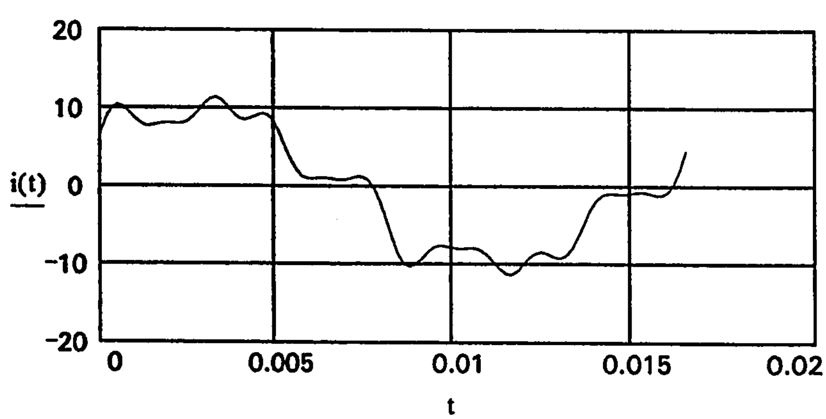
$t := 0, 0.167\cdot 10^{-3} .. m\cdot T$ **;this is for graphing the signals**

$v(t) := V\cdot\sin(w\cdot t)$ **;voltage signal** **;volt-amp product**

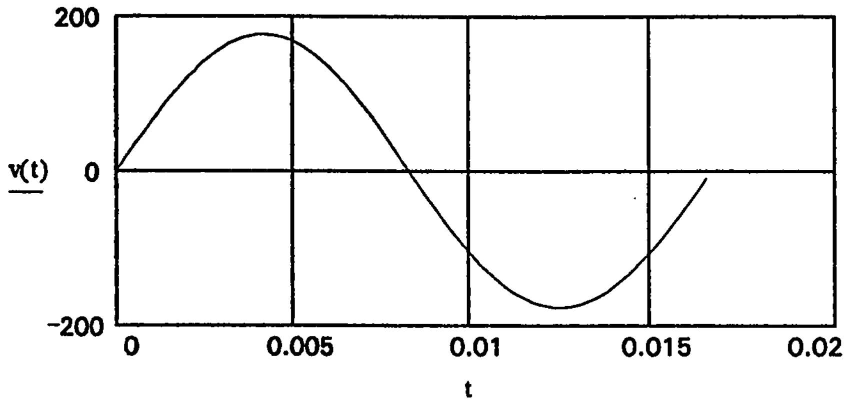
$i(t) := I1\cdot\sin(w\cdot t + the1) + I5\cdot\sin(w\cdot t\cdot 5 + the5) + I7\cdot\sin(w\cdot t\cdot 7 + the7) + I11\cdot\sin(w\cdot t\cdot 11 + the11)$
;current signal

$$Actual\_Power := \frac{1}{T}\cdot\int_0^T (v(t)\cdot i(t))\,dt$$

$Actual\_Power = 765.46554$

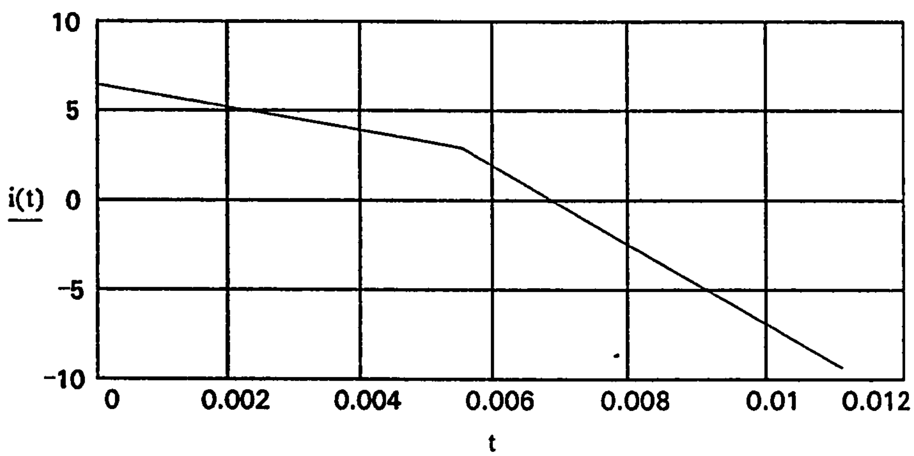


123

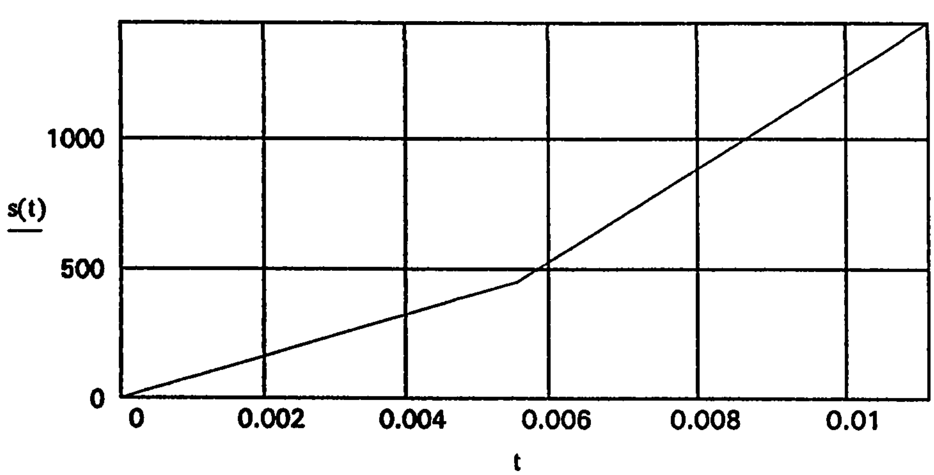


$$\Delta T := \frac{m \cdot T}{N}$$ **;sampling period**

$t := 0, \Delta T .. m \cdot T - 1 \cdot 10^{-3}$



$s(t) := v(t) \cdot i(t)$



123

$$\text{Power} := \frac{1}{N} \cdot \sum_{t} s(t)$$

Power = 626.44951

$$\text{Error\%} := \left| \frac{\text{Actual\_Power} - \text{Power}}{\text{Actual\_Power}} \right| \cdot 100$$

Error% = 18.16098

123

Method II
Zero-Crossing Technique
Case I.1

This simulates the Zero-crossing technique for measuring energy.

$\Delta T := 100 \cdot 10^{-6}$;this is for graphing the signals

$m := 7$;number of cycles

$f := 60$;waveform frequency

$T := \frac{1}{f}$;waveform period

$w := 2 \cdot \pi \cdot f$

$\Phi := \frac{\pi}{6}$ $pf := \cos(\Phi)$;power facror angle

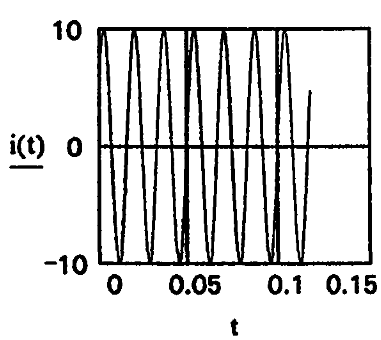
$t := 0, \Delta T .. m \cdot T$

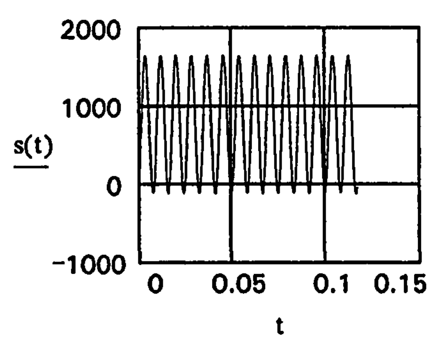
$current := 10$ $voltage := 125 \cdot \sqrt{2}$;amplitude values

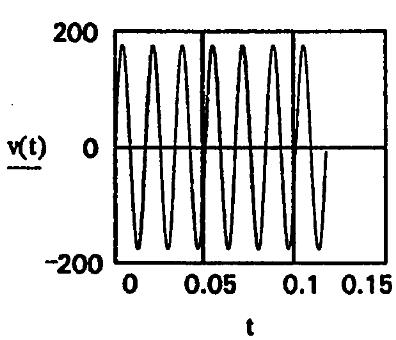
$i(t) := current \cdot \sin(w \cdot t + \Phi)$

$v(t) := voltage \cdot \sin(w \cdot t)$

$s(t) := v(t) \cdot i(t)$







123

$$Power := \frac{1}{2} \cdot current \cdot voltage \cdot \cos(\Phi)$$

$$v(t) := voltage \cdot \sin(w \cdot t)$$

$$s(t) := v(t) \cdot i(t)$$

$$Actual\_Power := \frac{1}{m \cdot T} \cdot \int_0^{m \cdot T} s(t)\, dt$$

$$Error\% := \left| \frac{Actual\_Power - Power}{Actual\_Power} \right| \cdot 100$$

$pf = 0.86603$ $m = 7$ $current = 10$ $voltage = 176.7767$

$f = 60$

$Actual\_Power = 765.46555$

$Power = 765.46554$

$Error\% = 1.80256 \cdot 10^{-7}$

123

Method II
Zero-crossing Technique
Case II.1

This simulates the Zero-crossing technique for measuring energy.

$N := 29$ **;number of samples**

$m := 1$ **;number of samples**

$f := 60$ **;waveform frequency** $T := \frac{1}{f}$ **;waveform period**

$V := 125 \cdot \sqrt{2}$ **;amplitude values**

$w := 2 \cdot \pi \cdot f$

$I1 := 1 \cdot 10$ $the1 := \frac{\pi}{6}$ $I5 := \frac{I1}{5}$ $the5 := \frac{\pi}{12}$ $I7 := \frac{I1}{7}$ $the7 := \frac{\pi}{6}$

$I11 := \frac{I1}{11}$ $the11 := \frac{\pi}{12}$ **;constructing the current harmonics**

$t := 0, 0.167 \cdot 10^{-3} .. m \cdot T$ **;this is for graphing the signals**

$v(t) := V \cdot \sin(w \cdot t)$ **;voltage signal**

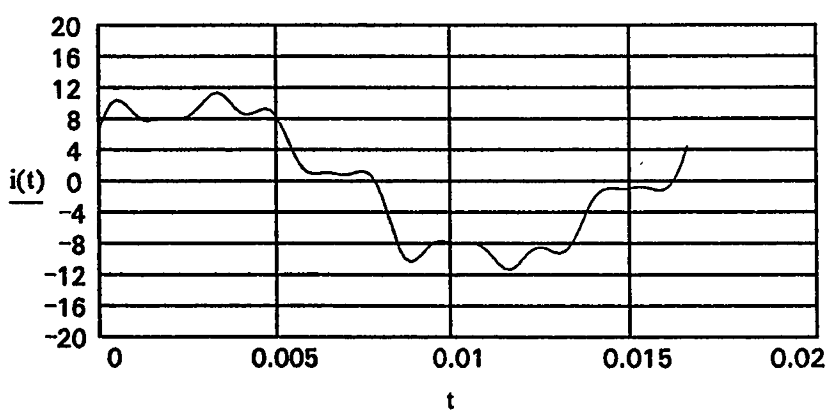
$i(t) := I1 \cdot \sin(w \cdot t + the1) + I5 \cdot \sin(w \cdot t \cdot 5 + the5) + I7 \cdot \sin(w \cdot t \cdot 7 + the7) + I11 \cdot \sin(w \cdot t \cdot 11 + the11)$

;current signal

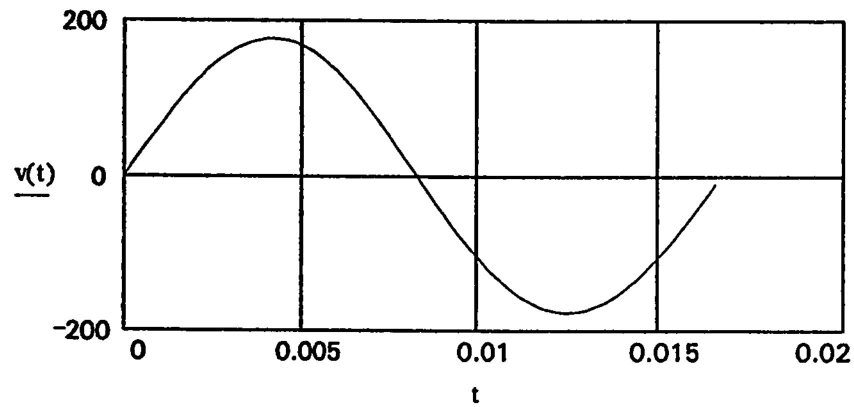
$s(t) := v(t) \cdot i(t)$

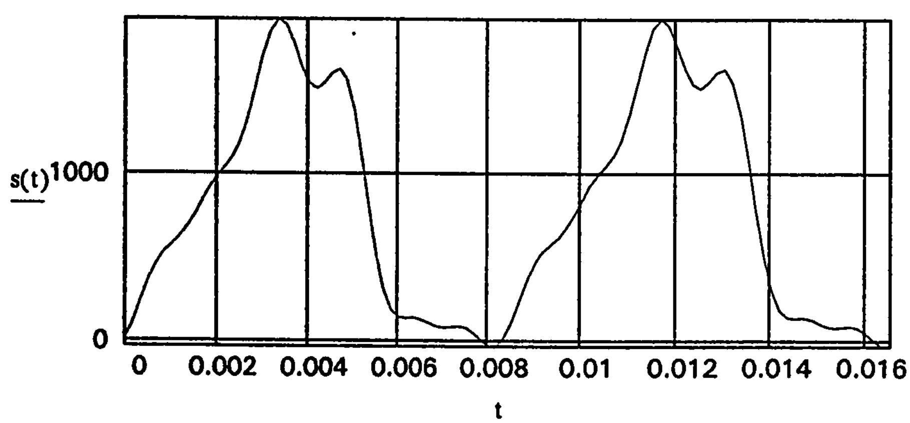
$$Actual\_Power := \frac{1}{m \cdot T} \cdot \int_{0}^{m \cdot T} s(t)\, dt$$

Actual_Power = 765.46554



Imax := 11.2 ;**Maximum Current from the graph**





$$\text{Power} := \frac{1}{2}\cdot V\cdot \text{Imax}\cdot\cos(\text{the1})$$

Power = 857.32141

$$\text{Error\%} := \left|\frac{\text{Actual\_Power} - \text{Power}}{\text{Actual\_Power}}\right|\cdot 100$$

Error% = 12

APPENDIX B

OPERATION PROGRAM

FOR

THE AUTOMATED BILLING SYSTEM

APPENDIX B

```
CLS
CLEAR
SCREEN 0,0
DEFINT A-Z
DIM TC#(100)
DIM N(2)
'
'INITIALIZE I/O PORTS
'PA0-7, PC0-7: OUTPUT PORT; PB0-7: INPUT PORT

AADDR = 768
BADDR = 769
CADDR = 770
T0ADDR=772
CNTADR = 771
CNTWORD=130
OUT CNTADR, CNTWORD
OUT AADDR,0
OUT CADDR,0
CR=0
BR=0
AR=0
'
'INITIALIZE DATA TRANSLATION CARD (A/D)

BASE.ADDRESS=&H2EE
COMMAND.ADDRESS=BASE.ADDRESS+1
STATUS.ADDRESS=BASE.ADDRESS+1
DATA.REGISTER=BASE.ADDRESS
COMMAND.WAIT=&H4
WRITE.WAIT=&H2
READ.WAIT=&H5
'
CCLEAR=&H1
CADIN=&HC
CSTOP=&HF
'
BASE.FACTOR#=4096
OUT COMMAND.REGISTER, CSTOP
TEMP=INP(DATA.REGISTER)
```

```
        WAIT STATUS.REGISTER, WRITE.WAIT, WRITE.WAIT
        WAIT STATUS.REGISTER, COMMAND.WAIT
        OUT COMMAND.REGISTER, CCLEAR
'
        'SET INITIAL VALUES

        TP#=0:TPC#=0:TF#=0:TFC#=0:TC#(89)=1:TC#(85)=2:PPeriod#=0
        PPeriod0#=0:PA=0:PMoney#=0:PC#=10:PMoney0#=0:TPCD#=0
        FPeriod#=0:FPeriod0#=0:FA=0:FMoney#=0:FC#=10:FMoney0#=0
        TFCD#=0:ACC#=0:TPeriod#=0:TPeriod0#=0:TA=0:TMoney#=0
        TMoney0#=0:TTC#=0:TTCD#=0
        VoltageStepDown#=74.835
        CurrentStepUp=1
'
        COLOR 2,0,0
        GOSUB SETT
        GOSUB SETSC
        GOSUB TDUPD
        GOSUB PASSW
        GOSUB CLRSC
        GOSUB SETM
'
        'UTILITIES CONNECTION (AC POWER, WATER, TELEPHONE)

        AR=AR+&H38
        OUT AADDR,AR
        PT0#=TIMER:FT0#=TIMER
'
        GOTO POWERB
'
SETT:   'SET TIME AND DATE

        PRINT
        PRINT
        PRINT" TIME =";TIME$
        PRINT
        INPUT" ENTER TIME";ANS$
        IF ANS$="" THEN ANS$=TIME$
        TIME$=ANS$
        PRINT
        PRINT
        PRINT" DATE =";DATE$
        PRINT
        INPUT" ENTER DATE";ANS1$
        IF ANS1$="" THEN ANS1$=DATE$
```

```
        DATE$=ANS1$
        RETURN
'
SETSC:  'SET SCREEN FRAMES

        CLS
        COLOR 14,0,0
        PRINT
        PRINT CHR$(201);
        FOR I=1 TO 78
        PRINT CHR$(205);
        NEXT I
        PRINT CHR$(187)
        LOCATE 3,1
        FOR I=1 TO 19
        PRINT CHR$(186)
        NEXT I
        PRINT CHR$(200)
        FOR I=1 TO 20
        LOCATE 2+I,80
        PRINT CHR$(186)
        NEXT I
        LOCATE 22,80
        PRINT CHR$(188)
        LOCATE 22,2
        FOR I=1 TO 78
        PRINT CHR$(205);
        NEXT I
        COLOR 9,0,0
        LOCATE 3,22
        PRINT CHR$(201);
        FOR I=1 TO 32
        PRINT CHR$(205);
        NEXT I
        PRINT CHR$(187)
        FOR I=1 TO 4
        LOCATE 3+I,22
        PRINT CHR$(186)
        NEXT I
        LOCATE 8,22
        PRINT CHR$(200)
        FOR I=1 TO 4
        LOCATE 3+I,55
        PRINT CHR$(186)
        NEXT I
```

```
        LOCATE 8,55
        PRINT CHR$(188)
        LOCATE 8,23
        FOR I=1 TO 32
        PRINT CHR$(205);
        NEXT I
        COLOR 12,0,0
        LOCATE 4,29
        PRINT " Automated Billing"
        LOCATE 5,23
        PRINT "  System for Public Utilities"
        LOCATE 6,26
        PRINT " Done By Saeed Al-Qatari"
        LOCATE 7,27
        COLOR 13,0,0
        PRINT " Ver. 2.0, August 1993"
        COLOR 7,0,0
        RETURN
'
SETM:   'SET METERS INDICATORS

        COLOR 14,0,0
        FOR I=1 TO 13
        LOCATE 8+I,26
        PRINT CHR$(186)
        NEXT I
        FOR I=1 TO 13
        LOCATE 8+I,53
        PRINT CHR$(186)
        NEXT I
        FOR I=2 TO 79
        LOCATE 19,I
        PRINT CHR$(205);
        NEXT I
        FOR I=2 TO 79
        LOCATE 10,I
        PRINT CHR$(205);
        NEXT I
        LOCATE 10,26
        PRINT CHR$(206)
        LOCATE 10,53
        PRINT CHR$(206)
        LOCATE 19,26
        PRINT CHR$(206)
        LOCATE 19,53
```


123

```
PRINT CHR$(206)
LOCATE 22,26
PRINT CHR$(202)
LOCATE 22,53
PRINT CHR$(202)
LOCATE 10,1
PRINT CHR$(204)
LOCATE 10,80
PRINT CHR$(185)
LOCATE 19,1
PRINT CHR$(204)
LOCATE 19,80
PRINT CHR$(185)
COLOR 11,0,0
LOCATE 9,7
PRINT "Power Charges"
LOCATE 9,31
PRINT "Water Flow Charges"
LOCATE 9,58
PRINT "Telephone Charges"
LOCATE 13,3
PRINT "Power:        kw.hr"
LOCATE 15,3
PRINT "Costs:        SR"
LOCATE 17,3
PRINT "Money:        SR"
LOCATE 13,28
PRINT "Flow :        10e3 L"
LOCATE 15,28
PRINT "Costs:        SR"
LOCATE 17,28
PRINT "Money:        SR"
LOCATE 11,55
PRINT "Status:"
LOCATE 13,55
PRINT "Dest. :"
LOCATE 15,55
PRINT "Costs :       SR"
LOCATE 17,55
PRINT "Money :       SR"
RETURN
'
PASSW:     'IDENTIFYING PASSWORD

           GOSUB CLRSC
```


123

```
        COLOR 11,0,0
        PASS$=""
        CHAR$=""
        BEEP 2
        LOCATE 13,4
        PRINT"ENTER PASSWORD FOLLOWED BY <ENTER>:"
        WHILE CHAR$ <> CHR$(13)
                CHAR$=INKEY$
                PASS$=PASS$+CHAR$
                GOSUB TDUPD
        WEND
        IF PASS$=("SAEED"+CHR$(13)) THEN
                RETURN
        END IF
        GOTO PASSW
'
CLRSC:  'CLEAR SCREEN

        FOR I=1 TO 6
        LOCATE I+9,4
        PRINT"                                        "
        NEXT I
        RETURN
'
TDUPD:  'TIME AND DATE UPDATE

        COLOR 10,0,0
        LOCATE 5,5
        PRINT"TIME:";TIME$
        LOCATE 5,60
        PRINT"DATE:";DATE$
        RETURN
'
POWERB: 'POWER BILLING

        GOSUB TELEB
        GOSUB TDUPD
        IF PA=1 THEN CARDI
        IF PMoney#=>TPCD# THEN POWERC
        IF (PPeriod#/3600)<.1 THEN
                COLOR 12,0,0
                LOCATE 20,3
                PRINT "Pay within";
                PRINT USING "##.##";(0.1-PPeriod#/3600);
                PRINT " hr"
```

```
            IF PPeriod#=0 THEN
                PPeriod0#=TIMER
                GOSUB TELEB
                GOTO CARDI
            ELSE
                GOSUB TELEB
                GOTO CARDI
            END IF
        END IF
        AR=AR-&H10 'DISCONNECT AC POWER
        OUT AADDR,AR
        PA=1':BEEP
        COLOR 12,0,0
        LOCATE 20,3
        PRINT "AC POWER REMOVED       "
'
CARDI:
        COLOR 12,0,0
        LOCATE 21,3
        PRINT "Insert card for loading"
'       BEEP
LOP26:
        STATUS=INP(BADDR)
        CARD=STATUS AND &H80
        IF CARD<>&H80 THEN
        K$=INKEY$
        IF K$="P" THEN
        GOTO LOP14
        END IF
        IF K$="F" THEN
        GOTO LOP16
        END IF
        IF K$="T" THEN
        GOSUB LOP18
        ELSE
        GOTO LOP26
        END IF
        END IF
        IF PA=1 THEN
                GOSUB TELEB
                GOTO FLOWB
        ELSE
                GOSUB TELEB
                GOTO POWERC
        END IF
```


123

```
LOP14:
        GOSUB LOADM
        PMoney#=PMoney#+ACC#
        ACC#=0
        IF PMoney#<TPCD# THEN
                COLOR 12,0,0
                LOCATE 21,3
                PRINT "Money is not enough"
                IF PA=1 THEN
                    GOSUB TELEB
                    GOTO LOP15
                ELSE
                    GOSUB TELEB
                    GOTO POWERC
                END IF
        END IF
        LOCATE 20,3
        PRINT"                    "
        COLOR 12,0,0
        LOCATE 21,3
        PRINT"Money is avialable      "
        IF PA=1 THEN
        AR=AR+&H10
        PA=0
        END IF
        PPeriod0#=0
'
POWERC: 'POWER CALCULATION

        COLOR 14,0,0
        AR=AR+&H40
        OUT AADDR,AR
        DELAY 0.1
        AR=AR-&H40
        OUT AADDR,AR
        DELAY 0.1
        ADCHANNEL=0
        GOSUB ADCONV
        Current#=DC.VALUE#-.205
        IF Current#<.1 THEN
                Current#=0
        END IF
        ADCHANNEL=1
        GOSUB ADCONV
        Voltage#=DC.VALUE#-.08
```


123

```
        GOSUB FREQM
        PULSE.PERIOD#=(COUNTER/917)*8.3333E-3
        TIME.DIFF#=ABS(8.3333E-3-PULSE.PERIOD#)
        PA#=TIME.DIFF#*180/8.3333E-3
        PF#=ABS(COS(PA#*3.141592654/180))
        Power#=(Voltage#*VoltageStepDown#)*(Current#/2)*PF#
        T#=TIMER-PT0#
        Power.kw.hr#=(Power#*T#)/(1000#*3600#)
        TP#=TP#+Power.kw.hr#
        LOCATE 13,9
        PRINT USING "#####.###";TP#;
        PT0#=TIMER
        TPC#=TP#*PC#
        LOCATE 15,9
        PRINT USING "#####.###";TPC#;
        TPCD#=TPCD#+Power.kw.hr#*PC#
        IF PMoney#=>TPCD# THEN CHARP
        IF PPeriod0#=0 THEN
                PPeriod#=0
                GOSUB TELEB
                GOTO LOP15
        END IF
        PPeriod#=TIMER-PPeriod0#
LOP15:
        TPCD#=TPCD#-PMoney#
        PMoney#=0
        LOCATE 17,9
        PRINT USING "#####.###";-TPCD#
'       BEEP
        GOSUB TELEB
        GOTO FLOWB
CHARP:
        PMoney#=PMoney#-TPCD#
        TPCD#=0
        LOCATE 17,9
        PRINT USING "#####.###";PMoney#
        GOSUB TELEB
'
FLOWB:  'WATER FLOW BILLING

        GOSUB TDUPD
        IF FA=1 THEN CARDFI
        IF FMoney#=>TFCD# THEN FLOWC
        IF (FPeriod#/3600)<.1 THEN
                COLOR 12,0,0
```

```
                LOCATE 20,28
                PRINT "Pay within";
                PRINT USING "##.##";(0.1-FPeriod#/3600);
                PRINT " hr"
                IF FPeriod#=0 THEN
                    FPeriod0#=TIMER
                    GOSUB TELEB
                    GOTO CARDFI
                ELSE
                    GOSUB TELEB
                    GOTO CARDFI
                END IF
        END IF
        AR=AR-&H20 'DISCONNECT SOLENOID VALVE
        OUT AADDR,AR
        FA=1':BEEP
        COLOR 12,0,0
        LOCATE 20,28
        PRINT "WATER REMOVED          "
'
CARDFI:
        COLOR 12,0,0
        LOCATE 21,28
        PRINT "Insert card for loading"
'       BEEP
LOP25:
        STATUS=INP(BADDR)
        CARD=STATUS AND &H80
        IF CARD<>&H80 THEN
        K$=INKEY$
        IF K$="P" THEN
        GOTO LOP14
        END IF
        IF K$="F" THEN
        GOTO LOP16
        END IF
        IF K$="T" THEN
        GOSUB LOP18
        ELSE
        GOTO LOP25
        END IF
        END IF
        IF FA=1 THEN
                GOSUB TELEB
                GOTO POWERB
```


123

```
        ELSE
                GOSUB TELEB
                GOTO FLOWC
        END IF
LOP16:
        GOSUB TELEB
        GOSUB LOADM
        FMoney#=FMoney#+ACC#
        ACC#=0
        IF FMoney#<TFCD# THEN
                COLOR 12,0,0
                LOCATE 21,28
                PRINT "Money is not enough    "
                IF FA=1 THEN
                    GOSUB TELEB
                    GOTO LOP17
                ELSE
                    GOSUB TELEB
                    GOTO FLOWC
                END IF
        END IF
        COLOR 12,0,0
        LOCATE 20,28
        PRINT"                "
        LOCATE 21,28
        PRINT"Money is avialable    "
        IF FA=1 THEN
        AR=AR+&H20
        OUT AADDR,AR
        FA=0
        END IF
        FPeriod0#=0
'
FLOWC:  'WATER FLOW CALCULATION

        COLOR 14,0,0
        Freq0#=380
        Flow0#=5
        ADCHANNEL=2
        GOSUB ADCONV
        FIN#=DC.VALUE#/(39E-12*9.6E6*10)
        Flow#=FIN#*Flow0#/Freq0#
        IF Flow#<0.2 THEN
                Flow#=0
        END IF
```

```
          T#=TIMER-FT0#
          Flow.kl#=(Flow#*T#)/(1000#*60#)
          TF#=TF#+Flow.kl#
          LOCATE 13,35
          PRINT USING "#####.###";TF#;
          FT0#=TIMER
          TFC#=TF#*FC#
          LOCATE 15,35
          PRINT USING "#####.###";TFC#;
          TFCD#=TFCD#+Flow.kl#*FC#
          IF FMoney#=>TFCD# THEN CHARF
          IF FPeriod0#=0 THEN
                    FPeriod#=0
                    GOSUB TELEB
                    GOTO LOP17
          END IF
          FPeriod#=TIMER-FPeriod0#
LOP17:
          TFCD#=TFCD#-FMoney#
          FMoney#=0
          LOCATE 17,35
          PRINT USING "#####.###";-TFCD#
          GOTO POWERB
CHARF:
          FMoney#=FMoney#-TFCD#
          TFCD#=0
          LOCATE 17,35
          PRINT USING "#####.###";FMoney#
          GOTO POWERB
'
TELEB:    'TELEPHONE BILLING

          IF TA=1 THEN
                    GOTO CARDTI
          END IF
          IF TMoney#=>TTCD# THEN TELEC
          IF (TPeriod#/3600)<.1 THEN
                    COLOR 12,0,0
                    LOCATE 20,55
                    PRINT "Pay within";
                    PRINT USING "##.##";(0.1-TPeriod#/3600);
                    PRINT " hr"
                    IF TPeriod#=0 THEN
                       TPeriod0#=TIMER
                       GOTO CARDTI
```

```
                ELSE
                    GOTO CARDTI
                END IF
        END IF
        AR=AR-&H08 'DISCONNECT TELEPHONE
        OUT AADDR,AR
        TA=1':BEEP
        COLOR 12,0,0
        LOCATE 20,55
        PRINT "TELEPHONE REMOVED    "
'
CARDTI:
        COLOR 12,0,0
        LOCATE 21,55
        PRINT "Insert card for loading"
'       BEEP
LOP24:
        STATUS=INP(BADDR)
        CARD=STATUS AND &H80
        IF CARD<>&H80 THEN
        K$=INKEY$
        IF K$="P" THEN
        GOTO LOP14
        END IF
        IF K$="F" THEN
        GOTO LOP16
        END IF
        IF K$="T" THEN
        GOSUB LOP18
        ELSE
        GOTO LOP24
        END IF
        END IF
        IF TA=1 THEN
                GOTO LOP22
        ELSE
                GOTO TELEC
        END IF
LOP18:
        GOSUB LOADM
        TMoney#=TMoney#+ACC#
        ACC#=0
        IF TMoney#<TTCD# THEN
                COLOR 12,0,0
                LOCATE 21,55
```

```
                PRINT "Money is not enough      "
                IF TA=1 THEN
                    GOTO LOP19
                ELSE
                    GOTO TELEC
                END IF
        END IF
        COLOR 12,0,0
        LOCATE 20,55
        PRINT"                  "
        LOCATE 21,55
        PRINT"Money is avialable     "
        IF TA=1 THEN
                AR=AR+&H08
                OUT AADDR,AR
                TA=0
        END IF
        TPeriod0#=0
'
TELEC:  'TELEPHONE CALCULATION

        STATUS=INP(BADDR)
        STATUS=STATUS AND &H20
        IF STATUS<>&H20 THEN CONT
        'OFF-HOOK/ON-HOOK DETECTOR
        COLOR 14,0,0
        LOCATE 11,63
        PRINT"Tele. is ON-HOOK "
        ONH=1
        GOTO NODE1
CONT:
        COLOR 14,0,0
        LOCATE 11,63
        PRINT"Tele. is OFF-HOOK"
        ONH=0
        IF LM=2 THEN LOP19
        IF C=1 THEN LOP21
'
DTMFR:  'DTMF RECEIVER ROTUINE

        AR=AR+04
        OUT AADDR,AR
        DELAY 0.1
        C=1
LOP21:
```

```
          PORTB = INP(BADDR)
          STATUS = PORTB AND &H10
          IF STATUS=&H10 THEN
                  RETURN
          END IF
          NUMBER1=INP(BADDR)
LOP20:
          PORTB = INP(BADDR)
          STATUS = PORTB AND &H10
          IF STATUS<>&H10 THEN LOP20
          BEEP
          NUMBER2 = NUMBER1 AND &H0F
          NUMBER=NUMBER2 XOR &H0F
          LM=LM+1
          N(LM)=NUMBER
          IF LM<>2 THEN LOP21
          CODE=N(1)*10+N(2)
          AR=AR-04
          OUT AADDR,AR
          C=0
LOP19:
          IF TC#(CODE)=0 THEN TELDC
          IF CR=1 THEN CHART
          AR=AR+&H01
          OUT AADDR,AR
          DELAY .1
          PORTB=INP(BADDR)
          STATUS=PORTB AND &H80
          IF STATUS=&H80 THEN
          AR=AR-&H01
          OUT AADDR,AR
                  RETURN
          END IF
          AR=AR-&H01
          OUT AADDR,AR
          TT0#=TIMER
          DELAY 1
          CR=1
          IF CODE=85 THEN
                  LOCATE 13,63
                  PRINT "QATIF "
          END IF
          IF CODE=89 THEN
                  LOCATE 13,63
                  PRINT "KHOBAR"
```

```
            END IF
            GOTO CHART
TELDC:
            AR=AR-&H08
            OUT AADDR,AR
            DELAY 2
            AR=AR+&H08
            OUT AADDR,AR
            COLOR 12,0,0
            LOCATE 20,54
            PRINT " INVALID CODE"
            LM=0:C=0:CR=0
            RETURN
NODE1:
            IF C=1 THEN
                    AR=AR-04
                    OUT AADDR,AR
                    C=0
            END IF
            IF CR=0 THEN
                    LM=0
                    IF TMoney#<TTCD# THEN
                       TPeriod#=TIMER-TPeriod0#
                       GOTO LOP22
                    END IF
                       GOTO LOP23
            END IF
CHART:
            IF ONH=1 THEN
                    LM=0:CR=0
            END IF
            TTC#=TTC#+TC#(CODE)*(TIMER-TT0#)/60
            TTCD#=TTCD#+TC#(CODE)*(TIMER-TT0#)/60
            TT0#=TIMER
            COLOR 14,0,0
            LOCATE 15,63
            PRINT USING "#####.###";TTC#
            IF TMoney#=>TTCD# THEN LOP23
            IF TPeriod0#=0 THEN
                    TPeriod#=0
                    GOTO LOP22
            END IF
            TPeriod#=TIMER-TPeriod0#
LOP22:
            TTCD#=TTCD#-TMoney#
```

```
            TMoney#=0
            COLOR 14,0,0
            LOCATE 17,63
            PRINT USING "#####.###";-TTCD#
'           BEEP
            RETURN
LOP23:
            TMoney#=TMoney#-TTCD#
            TTCD#=0
            LOCATE 17,63
            PRINT USING "#####.###";TMoney#
'           BEEP
            RETURN
'
FREQM:      'FREQUENCY MEASUREMENT

            CALL FREQUENCY (RESULT)
            COUNTER =RESULT
            FREQUENCY# =(917/RESULT)*60
            RETURN

            SUB FREQUENCY INLINE

            $INLINE  &H55
            $INLINE  &H8B, &HEC
            $INLINE  &HC4, &H7E, &H06
            $INLINE  &HBA, &H01, &H03

            $INLINE  &HB9, &H00, &H00

            $INLINE  &HEC
            $INLINE  &H24, &H40
            $INLINE  &H75, &HFB

            $INLINE  &HEC
            $INLINE  &H24, &H40
            $INLINE  &H74, &HFB

            $INLINE &H41
            $INLINE  &HEC
            $INLINE  &H24, &H40
            $INLINE  &H75, &HFA
            $INLINE  &H8B, &HC1
            $INLINE  &HAB
            $INLINE  &H5D
```

```
          END SUB
'
ADCONV:   'SINGLE OPERATION A/D CONVERSION

          BASE.ADDRESS=&H2EE
          COMMAND.REGISTER=BASE.ADDRESS+1
          STATUS.REGISTER=BASE.ADDRESS+1
          DATA.REGISTER=BASE.ADDRESS
          COMMAND.WAIT=&H4
          WRITE.WAIT=&H2
          READ.WAIT=&H5

          CCLEAR=&H1
          CADIN=&HC
          CSTOP=&HF

          BASE.FACTOR#=4096

          OUT COMMAND.REGISTER,CSTOP
          TEMP=INP(DATA.REGISTER)
          WAIT STATUS.REGISTER, WRITE.WAIT, WRITE.WAIT
          WAIT STATUS.REGISTER, COMMAND.WAIT
          OUT COMMAND.REGISTER, CCLEAR

          WAIT STATUS.REGISTER, WRITE.WAIT, WRITE.WAIT
          WAIT STATUS.REGISTER, COMMAND.WAIT
          OUT COMMAND.REGISTER, CADIN

          WAIT STATUS.REGISTER, WRITE.WAIT, WRITE.WAIT
          OUT DATA.REGISTER, 0

          WAIT STATUS.REGISTER, WRITE.WAIT, WRITE.WAIT
          OUT DATA.REGISTER, ADCHANNEL

          WAIT STATUS.REGISTER, READ.WAIT
          LOW=INP(DATA.REGISTER)
          WAIT STATUS.REGISTER, READ.WAIT
          HIGH=INP(DATA.REGISTER)
          DATA.VALUE#=HIGH*256+LOW

          WAIT STATUS.REGISTER, WRITE.WAIT, WRITE.WAIT
          WAIT STATUS.REGISTER, COMMAND.WAIT
          STATUS=INP(STATUS.REGISTER)
          IF (STATUS AND &H80) THEN 2000
```


123

```
          FACTOR#=(10/BASE.FACTOR#)/1
          UNI.VOLTS#=DATA.VALUE#*FACTOR#
          BI.VOLTS#=UNI.VOLTS#*2-(10/1)
          DC.VALUE#=BI.VOLTS#
          RETURN
'
2000      PRINT
          PRINT"ERROR"
          PRINT
          END
'
LOADM:    'LOADDING MONEY FOR CARD READER

          AR=AR-&H08
          OUT AADDR,AR
LOP27:
          STATUS=INP(BADDR)
          CARD=STATUS AND &H80
          IF CARD<>&H80 THEN
                 GOSUB TDUPD
                 ACC#=ACC#+1
                 AR=AR+&H80
                 OUT AADDR,AR
                 DELAY 0.4
                 AR=AR-&H80
                 OUT AADDR,AR
                 DELAY 0.4
                 GOTO LOP27
          END IF
          AR=AR+&H08
          OUT AADDR,AR
          RETURN

          END
```

APPENDIX C

MAINTENANCE PROGRAM

FOR

THE AUTOMATED BILLING SYSTEM

APPENDIX C

```
CLS
CLEAR
SCREEN 0,0
DEFINT A-Z
'
'INITIALIZE I/O PORTS
'PA0-7, PC0-7: OUTPUT PORTS; PB0-7: INPUT PORTS

AADDR = 768
BADDR = 769
CADDR = 770
T0ADDR=772
CNTADR = 771
CNTWORD=130
OUT CNTADR, CNTWORD
OUT AADDR,0
OUT CADDR,0
CR=0
BR=0
AR=0
'
'INITIALIZE DATA TRANSLATION CARD (A/D)

BASE.ADDRESS=&H2EE
COMMAND.ADDRESS=BASE.ADDRESS+1
STATUS.ADDRESS=BASE.ADDRESS+1
DATA.REGISTER=BASE.ADDRESS
COMMAND.WAIT=&H4
WRITE.WAIT=&H2
READ.WAIT=&H5
'
CCLEAR=&H1
CADIN=&HC
CSTOP=&HF
'
BASE.FACTOR#=4096
OUT COMMAND.REGISTER, CSTOP
TEMP=INP(DATA.REGISTER)
WAIT STATUS.REGISTER, WRITE.WAIT, WRITE.WAIT
```

```
        WAIT STATUS.REGISTER, COMMAND.WAIT
        OUT COMMAND.REGISTER, CCLEAR
'
        'SET CONSTANT VALUES

        VoltageStepDown#=74.835
        CurrentStepUp=1
'
        'CONNECT AC POWER SOURCE AND TELEPHONE LINE

        AR=AR+&H18
        OUT AADDR,AR
'
        'SCREEN CONFIGURATION

        COLOR 2,0,0
        GOSUB SETT
        GOSUB SETSC
        GOSUB TDUPD
        GOSUB PASSW
        GOTO MENU

        END
'
SETT:   'SET TIME AND DATE

        PRINT
        PRINT
        PRINT" TIME =";TIME$
        PRINT
        INPUT" ENTER TIME";ANS$
        IF ANS$="" THEN ANS$=TIME$
        TIME$=ANS$
        PRINT
        PRINT
        PRINT" DATE =";DATE$
        PRINT
        INPUT" ENTER DATE";ANS1$
        IF ANS1$="" THEN ANS1$=DATE$
        DATE$=ANS1$
        RETURN
'
SETSC:  'SET SCREEN FRAMES

        CLS
```


123

```
COLOR 4,0,0
PRINT
PRINT CHR$(201);
FOR I=1 TO 78
PRINT CHR$(205);
NEXT I
PRINT CHR$(187)
LOCATE 3,1
FOR I=1 TO 19
PRINT CHR$(186)
NEXT I
PRINT CHR$(200)
FOR I=1 TO 20
LOCATE 2+I,80
PRINT CHR$(186)
NEXT I
LOCATE 22,80
PRINT CHR$(188)
LOCATE 22,2
FOR I=1 TO 78
PRINT CHR$(205);
NEXT I

COLOR 14,0,0
LOCATE 3,22
PRINT CHR$(201);
FOR I=1 TO 32
PRINT CHR$(205);
NEXT I
PRINT CHR$(187)
FOR I=1 TO 4
LOCATE 3+I,22
PRINT CHR$(186)
NEXT I
LOCATE 8,22
PRINT CHR$(200)
FOR I=1 TO 4
LOCATE 3+I,55
PRINT CHR$(186)
NEXT I
LOCATE 8,55
PRINT CHR$(188)
LOCATE 8,23
FOR I=1 TO 32
PRINT CHR$(205);
```

```
        NEXT I
        COLOR 3,0,0
        LOCATE 4,29
        PRINT " Automated Billing"
        LOCATE 5,23
        PRINT "  System for Public Utilities"
        LOCATE 6,26
        PRINT " Done By Saeed Al-Qatari"
        LOCATE 7,27
        COLOR 5,0,0
        PRINT " Ver. 2.0, August 1993"
        COLOR 7,0,0
        KEY ON
        RETURN
'
CLRSC:  'CLEAR SCREEN

        FOR I=1 TO 12
        LOCATE I+9,4
        PRINT"                                    "
        NEXT I
        RETURN
'
TDUPD:  'TIME AND DATE UPDATE

        COLOR 2,0,0
        LOCATE 5,5
        PRINT"TIME:";TIME$
        LOCATE 5,60
        PRINT"DATE:";DATE$
        RETURN
'
FREQM:  'FREQUENCY MEASUREMENT

        CALL FREQUENCY (RESULT)
        COUNTER =RESULT
        FREQUENCY# =(917/RESULT)*60
        RETURN

        SUB FREQUENCY INLINE

        $INLINE     &H55
        $INLINE     &H8B, &HEC
        $INLINE     &HC4, &H7E, &H06
        $INLINE     &HBA, &H01, &H03
```

```
        $INLINE     &HB9, &H00, &H00

        $INLINE     &HEC
        $INLINE     &H24, &H40
        $INLINE     &H75, &HFB

        $INLINE     &HEC
        $INLINE     &H24, &H40
        $INLINE     &H74, &HFB

        $INLINE     &H41
        $INLINE     &HEC
        $INLINE     &H24, &H40
        $INLINE     &H75, &HFA
        $INLINE     &H8B, &HC1
        $INLINE     &HAB
        $INLINE     &H5D

        END SUB
'
ADCONV: 'SINGLE OPERATION A/D CONVERSION
'
        DEFINT A-Z
        BASE.ADDRESS=&H2EE
        COMMAND.REGISTER=BASE.ADDRESS+1
        STATUS.REGISTER=BASE.ADDRESS+1
        DATA.REGISTER=BASE.ADDRESS
        COMMAND.WAIT=&H4
        WRITE.WAIT=&H2
        READ.WAIT=&H5

        CCLEAR=&H1
        CADIN=&HC
        CSTOP=&HF

        BASE.FACTOR#=4096

        OUT COMMAND.REGISTER,CSTOP
        TEMP=INP(DATA.REGISTER)
        WAIT STATUS.REGISTER, WRITE.WAIT, WRITE.WAIT
        WAIT STATUS.REGISTER, COMMAND.WAIT
        OUT COMMAND.REGISTER, CCLEAR

        WAIT STATUS.REGISTER, WRITE.WAIT, WRITE.WAIT
```


123

```
            WAIT STATUS.REGISTER, COMMAND.WAIT
            OUT COMMAND.REGISTER, CADIN

            WAIT STATUS.REGISTER, WRITE.WAIT, WRITE.WAIT
            OUT DATA.REGISTER, 0

            WAIT STATUS.REGISTER, WRITE.WAIT, WRITE.WAIT
            OUT DATA.REGISTER, ADCHANNEL

            WAIT STATUS.REGISTER, READ.WAIT
            LOW=INP(DATA.REGISTER)
            WAIT STATUS.REGISTER, READ.WAIT
            HIGH=INP(DATA.REGISTER)
            DATA.VALUE#=HIGH*256+LOW

            WAIT STATUS.REGISTER, WRITE.WAIT, WRITE.WAIT
            WAIT STATUS.REGISTER, COMMAND.WAIT
            STATUS=INP(STATUS.REGISTER)
            IF (STATUS AND &H80) THEN 2000

            FACTOR#=(10/BASE.FACTOR#)/1
            UNI.VOLTS#=DATA.VALUE#*FACTOR#
            BI.VOLTS#=UNI.VOLTS#*2-(10/1)
            DC.VALUE#=BI.VOLTS#
            RETURN
'
2000        PRINT
            PRINT"ERROR"
            PRINT
            END
'
PCALC:      'AC POWER CALCULATION

                        AR=AR+&H40
                        OUT AADDR,AR
                        DELAY 0.1
                        AR=AR-&H40
                        OUT AADDR,AR
                        DELAY 0.1
                        ADCHANNEL=0
                        GOSUB ADCONV
                        Current#=DC.VALUE#-.205
                        ADCHANNEL=1
                        GOSUB ADCONV
                        Voltage#=DC.VALUE#-.07
```

```
                    GOSUB FREQM
                    PULSE.PERIOD#=(COUNTER/917)*8.3333E-3
                    TIME.DIFF#=ABS(8.3333E-3-PULSE.PERIOD#)
                    PA#=TIME.DIFF#*180/8.3333E-3
            PF#=COS(PA#*3.141592654/180)
            Power#=(Voltage#*VoltageStepDown#)*(Current#/2)*PF#
            LOCATE 15,5
            PRINT" * Voltage      = ";
            PRINT USING "###.###";VoltageStepDown#*Voltage#/SQR(2);
            PRINT " Vrms"
            LOCATE 16,5
            PRINT" * Current      = ";
            PRINT USING "###.###";Current#/SQR(2);
            PRINT " Arms"
            LOCATE 17,5
            PRINT" * Power Factor = ";
            PRINT USING "###.###";PF#
            LOCATE 18,5
            PRINT" * Power        = ";
            PRINT USING "###.###";Power#;
            PRINT " Watt"
LOP03:
            K$=INKEY$:IF K$="" THEN LOP03
            RETURN
'
STATUS:     'DETECT DTMF RECEIVER STATUS

            STATUS=INP(BADDR)
            RETURN
'
OFONH:      'OFF-HOOK/ON-HOOK DETECTOR

            LOCATE 13,5
            PRINT" * PRESS (X) TO EXIT."
            LOCATE 16,5
            PRINT" * Telephone Status:";
            LOCATE 16,26
            PRINT"Telephone is ON-HOOK   "
LOP09:
            K$=INKEY$
            IF K$="X" THEN
                  RETURN
            END IF

OFFON:
```

```
        GOSUB TDUPD
        STATUS=INP(BADDR)
        STATUS=STATUS AND &H20
        IF STATUS<>&H20 THEN CONT
        GOTO OFONH
CONT:
        LOCATE 16, 26
        PRINT "Telephone is OFF-HOOK  "
        GOTO LOP09
'
FLOWC:  'FLOW RATE CALCULATION

        Freq0=380
        Flow0=5
        ADCHANNEL=2
        LOCATE 13,5
        PRINT" * PRESS (X) TO EXIT."
        LOCATE 16,5
        PRINT" * Flow Rate: ";
        AR=AR+&H20
        OUT AADDR,AR
        DELAY 0.5
LOP10:
        K$=INKEY$
        IF K$="X" THEN
                AR=AR-&H20
                OUT AADDR,AR
                RETURN
        END IF
        GOSUB TDUPD
        GOSUB ADCONV
        FIN#=DC.VALUE#/(39E-12*9.6E6*10)
        Flow#=FIN#*Flow0/Freq0
        IF Flow#<0.2 THEN
        Flow#=0
        END IF
        LOCATE 16,22
        PRINT "                    "
        LOCATE 16,22
        PRINT USING "###.###";Flow#;
        PRINT " Liters/Min."
        DELAY 0.5
        GOTO LOP10
'
PASSW:
```

memodisk/A:\pcu3276.doc
cc: File: 35.50.45, 35.50.50, 35.50.65

123

```
          GOSUB CLRSC
          COLOR 15,0,0
          PASS$=""
          CHAR$=""
          BEEP 2
          LOCATE 13,4
          PRINT"ENTER PASSWORD FOLLOWED BY <ENTER>:"
          WHILE CHAR$ <> CHR$(13)
                    CHAR$=INKEY$
                    PASS$=PASS$+CHAR$
          WEND
          IF PASS$=("SAEED"+CHR$(13)) THEN
                    RETURN
          END IF
          GOTO PASSW
'
CVACM:    'CURRENT & VOLTAGE AC MEASUREMRNT

          COLOR 7,0,0
          LOCATE 10,4
          PRINT"Please choose one of the followings:"
          LOCATE 12,4
          PRINT"1. AC Current Measurement."
          LOCATE 13,4
          PRINT"2. AC Voltage Measurement."
          LOCATE 19,4
          PRINT"X. Exit."
'
SCAN02:   'UPDATE RIME AND DATE

          GOSUB TDUPD
          K$=INKEY$
          IF K$="" THEN SCAN02
'
          IF K$="1" THEN
                    ADCHANNEL=0
                    GOSUB CLRSC
                    AR=AR+&H40
                    OUT AADDR,AR
                    DELAY 0.1
                    AR=AR-&H40
                    OUT AADDR,AR
                    DELAY 0.1
                    GOSUB ADCONV
                    LOCATE 15,5
```


123

```
                        PRINT" * Current = ";
                        PRINT USING "###.###";(DC.VALUE#-.205)/SQR(2);
                        PRINT " Amp.(rms)"
LOP01:
            K$=INKEY$:IF K$="" THEN LOP01
                        GOSUB CLRSC
                        GOTO CVACM
            END IF
'
            IF K$="2" THEN
                        ADCHANNEL=1
                        GOSUB CLRSC
                        AR=AR+&H40
                        OUT AADDR,AR
                        DELAY 0.1
                        AR=AR-&H40
                        OUT AADDR,AR
                        DELAY 0.1
                        GOSUB ADCONV
                        LOCATE 15,5
                        PRINT" * Voltage = ";
                        PRINT USING "###.###";(DC.VALUE#-
                                                .04)*74.84/SQR(2)-2;
                        PRINT " Volt(rms)"
LOP02:
            K$=INKEY$:IF K$="" THEN LOP02
                        GOSUB CLRSC
                        GOTO CVACM
            END IF
'
            IF K$="X" OR K$="x" THEN
                        RETURN
            END IF
            BEEP
            GOTO SCAN02
'
PFCAL:      'POWER FACTOR CALCULATION

            GOSUB FREQM
            PULSE.PERIOD#=(COUNTER/920)*8.3333E-3
            TIME.DIFF#=ABS(8.3333E-3-PULSE.PERIOD#)
            PA#=TIME.DIFF#*180/8.3333E-3
            PF#=COS(PA#*3.141592654/180)
            LOCATE 15,5
            PRINT" * Counter = ";COUNTER
```

```
        LOCATE 17,5
        PRINT" * Period  = ";
        PRINT USING "###.###";TIME.DIFF#;
        PRINT " Sec."
        LOCATE 19,5
        PRINT" * Phase angle = ";
        PRINT USING "###.###";PA#;
        PRINT " Deg."
LOP11:
        K$=INKEY$:IF K$="" THEN LOP11
        RETURN
'
DTMFR:  'DTMF RECEIVER ROTUINE

        AR=AR+02
        OUT AADDR,AR
        DELAY 0.5
        AR=AR+04
        OUT AADDR,AR
        DELAY 0.5
LOP05:
        LOCATE 13,5
        PRINT" * PRESS (X) TO EXIT."
        LOCATE 14,5
        PRINT" * PRESS (C) TO CLEAR SCREEN."
        LOCATE 16,5
        PRINT" * NUMBER =";
LOP06:
        K$=INKEY$
        IF K$="C" THEN
                GOSUB CLRSC
                GOTO LOP05
        END IF
        IF K$="X" THEN
                AR=AR-04
                OUT AADDR,AR
                AR=AR-02
                OUT AADDR,AR
                RETURN
        END IF
        PORTB = INP(BADDR)
        STATUS = PORTB AND &H10
        IF STATUS=&H10 THEN LOP06
        NUMBER1=INP(BADDR)
LOP07:
```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```
          PORTB = INP(BADDR)
          STATUS = PORTB AND &H10
          IF STATUS<>&H10 THEN LOP07
          BEEP
          NUMBER2 = NUMBER1 AND &H0F
          NUMBER=NUMBER2 XOR &H0F
          IF NUMBER = 10 THEN NUMBER= 0
          IF NUMBER = 11 THEN
                    NUMBER$ = " * "
                    GOTO LOP08
          END IF
          IF NUMBER = 12 THEN
                    NUMBER$ = " # "
                    GOTO LOP08
          END IF
          PRINT NUMBER;
          GOTO LOP06
LOP08:
          PRINT NUMBER$;
          GOTO LOP06
'
FREQ:     'FREQUENCY MEASUREMENT ROUTINE

                    GOSUB CLRSC
                    GOSUB FREQM
                    LOCATE 15,5
                    PRINT" * Frequency =";
                    PRINT USING "###.###";FREQUENCY#;
                    PRINT " Hz"
LOP12:
          K$=INKEY$:IF K$="" THEN LOP12
                    RETURN
'
MENU:     'MENUE LIST
          GOSUB CLRSC
          COLOR 7,0,0
          FOR I=1 TO 10
          LOCATE I+9,4
          PRINT"                                        "
          NEXT I
          LOCATE 10,4
          PRINT"Please choose one of the followings:"
          LOCATE 12,4
          PRINT"1. AC Current & Voltage measurement."
          LOCATE 13,4
```

```
        PRINT"2. Frequency measurement < 10kHz (Port B-6)."
        LOCATE 14,4
        PRINT"3. AC Power measurement."
        LOCATE 15,4
        PRINT"4. DTMF Receiver."
        LOCATE 16,4
        PRINT"5. On & Off-Hook Detector."
        LOCATE 17,4
        PRINT"6. Water Flowrate measurement."
        LOCATE 18,4
        PRINT"7. Power Factor Angle measurement."
        LOCATE 19,4
        PRINT"8. Card Reader Test."
        LOCATE 21,4
        PRINT"X. Exit."
'
SCAN:   'SCAN KEYBOARD
        GOSUB TDUPD
        K$=INKEY$
        IF K$="" THEN SCAN
'
        IF K$="1" THEN
                GOSUB CLRSC
                GOSUB CVACM
                GOTO MENU
        END IF
'
        IF k$="2" THEN
                GOSUB CLRSC
                GOSUB FREQ
                GOTO MENU
        END IF
'
        IF K$="3" THEN
                GOSUB CLRSC
                GOSUB PCALC
                GOTO MENU
        END IF
'
        IF K$="4" THEN
                GOSUB CLRSC
                GOSUB DTMFR
                GOTO MENU
        END IF
'
```

```
        IF K$="5" THEN
                GOSUB CLRSC
                GOSUB OFONH
                GOTO MENU
        END IF
'
        IF K$="6" THEN
                GOSUB CLRSC
                GOSUB FLOWC
                GOTO MENU
        END IF
'
        IF K$="7" THEN
                GOSUB CLRSC
                GOSUB PFCAL
                GOTO MENU
        END IF
'
        IF K$="8" THEN
                GOSUB CLRSC
                GOSUB CARDR
                GOTO MENU
        END IF
'
        IF K$="X" OR K$="x" THEN
                END
        END IF
        BEEP
        GOTO SCAN
'
CARDR:  'CARD READER ROTUINE

        CARD.IN=INP(BADDR)
        STATUS=CARD.IN AND &H80
        IF STATUS<>0 THEN NOMONY
MONY:
        GOSUB CLRSC
        LOCATE 15,4
        PRINT "* MONY IS AVIALABLE FOR DEBIT."
        LOCATE 17,4
        PRINT "* PRESS (D) TO DEBIT, (X) TO EXIT."

        K$=INKEY$
        IF K$="D" THEN
                AR=AR+&H80
```

```
                OUT AADDR,AR
                DELAY .1
                AR=AR-&H80
                OUT AADDR,AR
        END IF
LOP13:
        IF K$="X" THEN
                RETURN
        END IF

        GOSUB TDUPD
        GOTO CARDR

NOMONY:
        GOSUB CLRSC
        LOCATE 15,4
        PRINT "* NO MONY IS AVIALABLE FOR DEBIT.
        LOCATE 17,4
        PRINT "* PRESS (X) TO EXIT."
        K$=INKEY$
        GOTO LOP13

        END
```

APPENDIX D

INPUT/OUTPUT INTERFACING CARD

APPENDIX D

INPUT/OUTPUT INTERFACING CARD

The interfacing module card consists of 3-port I/O chip (8255), 3-timer running at 2 MHz (8253), and decoding circuit. The complete circuit structure is shown in Figure D-1. This card plugs into an expansion unit or system unit expansion slot. Data, addresses, control signals, and voltage requirements are provided through a 2 by 31 position card-edge tab.

This card also accommodates a D-shell connector for interface with outside world using 25-wire cable. The card design is shwon in Figure D-2.

The 8255 is a programmable peripheral interface (PPI) chip. It is used to interface peripheral equipment to the CPU system bus. The 8255 interfaces has a bidirectional data bus with three programmable I/O ports, and control logic.

The functional configuration of the 8255 is programmed during program initialization. The tri-state bidirectional buffered data bus XD0 through XD7 connects with the 8255 on pins 27 to 34. Data is transferred by the buffer under CPU control. PPI control words and status information are also passed back and forth through this data bus buffer.

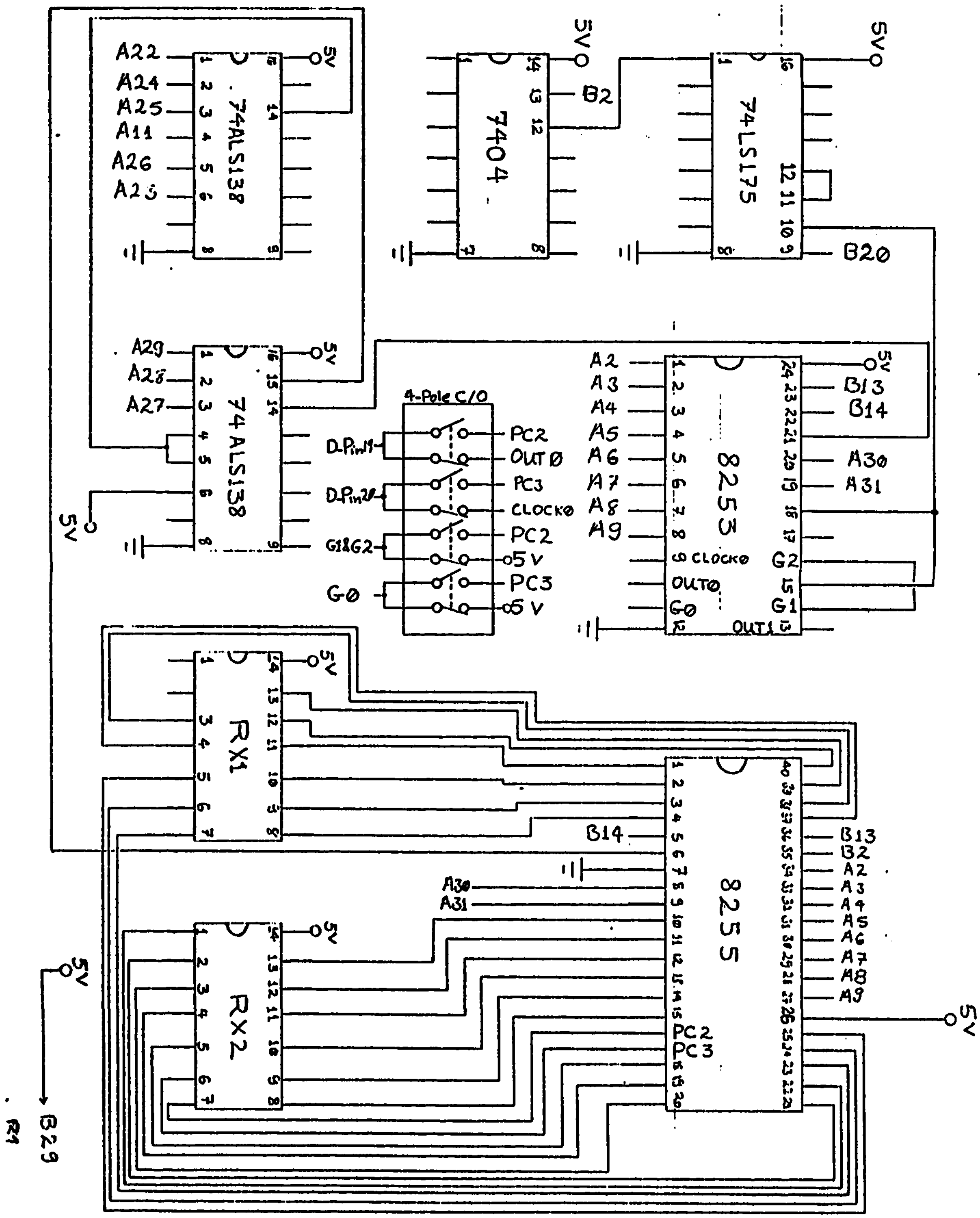
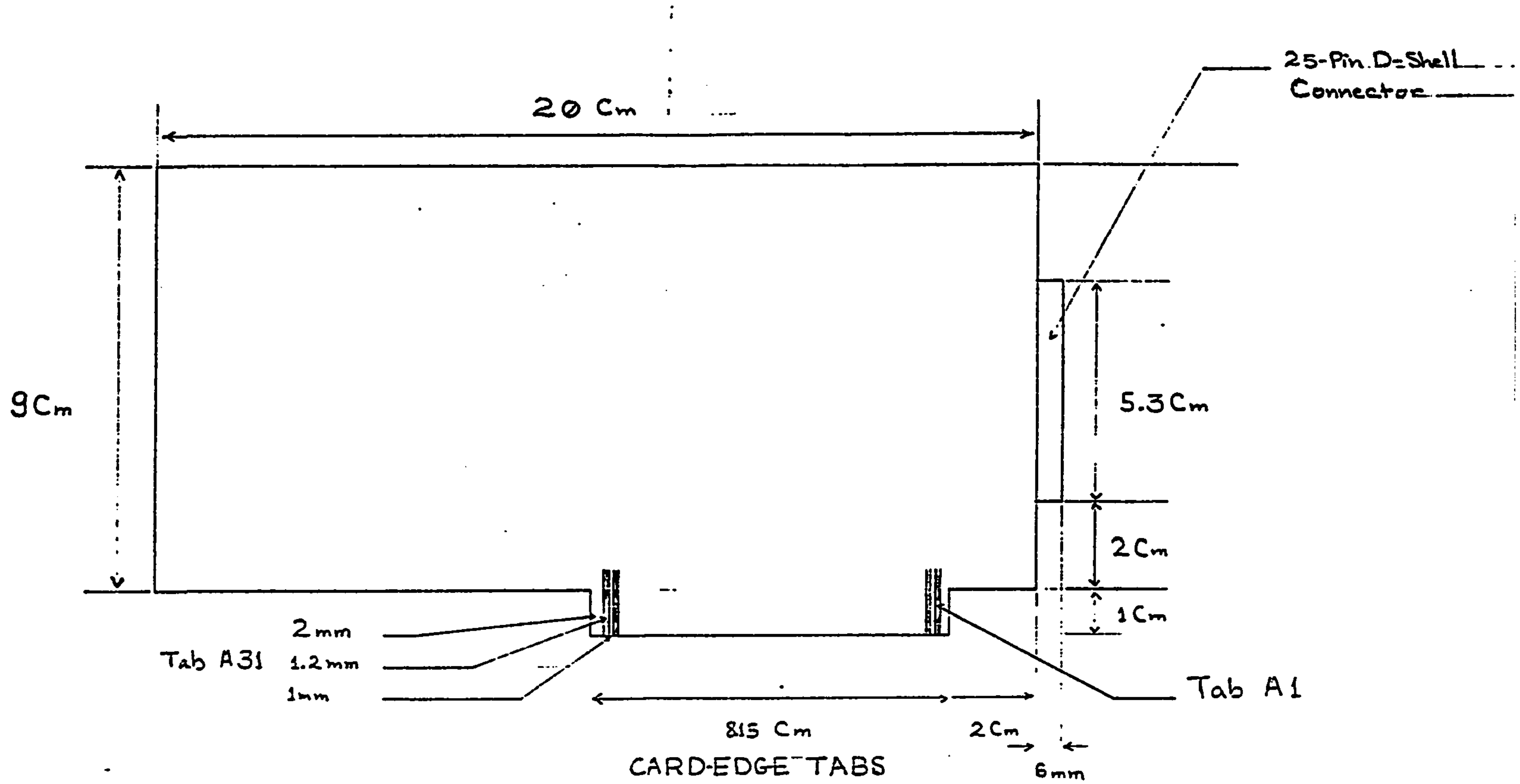


FIGURE D-1, I/O CIRCUIT STRUCTURE



Note:

Tabs are on each side :

1. Side A shown, 31 Tab: From A1 to A31
2. Side B other side, 31 Tab: From B1 to B31

FIGURE D-2, I/O CARD DESIGN

The read/write control logic accepts six input control signals that manage the operation of this device. An active low XIOR on pin 5 enables 8255 to send data or status to the CPU over the data bus, which lets the CPU reads from 8255. An active low XIOW on pin 36 enables the CPU to write data or control words into 8255. XA0 and XA1 on pins 8 and 9 respectively are used with XIOR and XIOW to select one of the three I/O ports or internal control registers. An active low Chip Select (CS) on pin 6 enables the communication between the 8255 and the CPU. The select address is decoded by connecting XA2 to XA9 to two 3 to 8 decoder multiplexer (74LS138). The control addresses for the I/O ports is provided in Tables 1 and 2.

Each bit of the I/O ports (port A, port B and port C) is connected to 1Kohm pull-up resistor, which is connected to +5 V. This allow the ports to drain current not to source current for chip protection. Port A is an 8-bit data output latch/buffer and 8-bit data input latch. Port B is an 8-bit data output latch/buffer and 8-bit data input buffer. Port C is an 8-bit data output latch/buffer and 8-bit data input latch/buffer (no latch for input). This port can be divided into two 4-bit ports under the mode control. Each 4-bit port contains a 4-bit latch and it can be used for the control signal outputs and status signal inputs in conjunction with ports A and B.

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The 8253 is called programmable interval timer. This peripheral device is organized as three independent 16-bit down counters, each with a count rate up to 2 MHz. The input clock to 8253 at pin 15 comes from 74LS175 quad D flip-flop, which divides the input clock form computer (4.772727MHz) by four. The 7404 between the computer input clock and D flip-flops works as a buffer. As a result, the clock input to 8253 on pin 5 will be 1.1931875MHz. This causes 8253 to count at 1.1931875MHz rate. The OUT0, OUT1 and OUT2 occur at frequency determined by the input clock divided by the a software programmable 16-bit number. 8253 is used to generate accurate time delays under software control minimizing program overhead.

Upon 8253 initialization, each timer is configured via a unique control word and an initialized value set by the CPU. These data enter 8253 on pins 1 through 8 (XD0 through XD7). The software writes out to 8253 a mode control word and the programmed number of count desired. The mode control word is an 8-bit word, which initializes a particular counter with the desired mode. Six modes are available:

Mode 0: Interrupt on terminal count.

Mode 1: Programmable one-shot.

Mode 2: Divide by N rate generator.

Mode 3: Divide by N square wave.

Mode 4: Software triggered strobe.

Mode 5: Hardware triggered strobe.

The 8-bit of the mode control byte are allocated as follows:

Bit 0: Count in binary to 0, otherwise count in BCD.

Bit 1-3: Defines which mode is desired.

Bit 4,5: Read/load sequence.

Bit 6,7: Defines which counter is to be affected.

Once, the control word has been received, a count register in each counter is preloaded in the sequence defined by the mode control word. Each counter counts down to zero so that the value loaded into the count register decrements with each input clock pulse. Loading all zeros into a count register causes that counter to count down from a maximum value (65,535 for binary, 9,999 for BCD). Once programmed, the counting operation is completely independent. Upon count start, the 8253 causes each counter to count down until the preset delay value reaches zero. At this point, the zeroed counter generates a pulse as count-complete output flag showing it has completed its tasks.

APPENDIX E

CALL PROCEDURE

APPENDIX E

CALL PROCEDURE

The connection between the call originator and the called phone is established by performing the following steps:

1. **Initiating a call:** When the "receiver" handset is removed from its cradle; this is called the off-hook condition. The off-hook signal tells the exchange that someone wants to make a call. The exchange returns a dial tone to the called phone to let the caller knows that the exchange is ready to accept a telephone number. The telephone number also may be referred to as an address.

2. **Sending a Number:** Nowdays, there are different ways to send a telephone number. The numbers can be sent using dial pulses, audio tones, or digital signal.

3. **Connecting the Phones:** Various ways are used to automatically connect the calling and called phones. Some of them use switches and relays to perform the connections, while the others use TDM. If the called phone handset is off-hook when the connection is attempted, a busy tone generated by the central office is returned to the calling phone. Otherwise, a ringing

signal is sent to the called phone to alert the called party that a call is waiting. At the same time, a ringback tone is returned to the calling phone to indicate that the called phone is ringing.

4. **Answering the Call:** When the called party removes the handset in response to a ring, the loop to that phone is completed by its closed switchhook and loop current flows through the called telephone. The central office then removes the ringing signal and the ringback tone from the circuit.

5. **Answer Supervision:** Answer supervision involves disconnecting the ringing current when the called party answers. In some of the switches an interruption of the circuit or reversing the polarities of the tip-ring pair is required [9].

6. **Ending the Call:** In most to-days switching systems, the call is ended (the connection is released) only when the calling party goes on-hook.

APPENDIX F

MICROCONTROLLERS AND MICROPROCESSORS

APPENDIX F

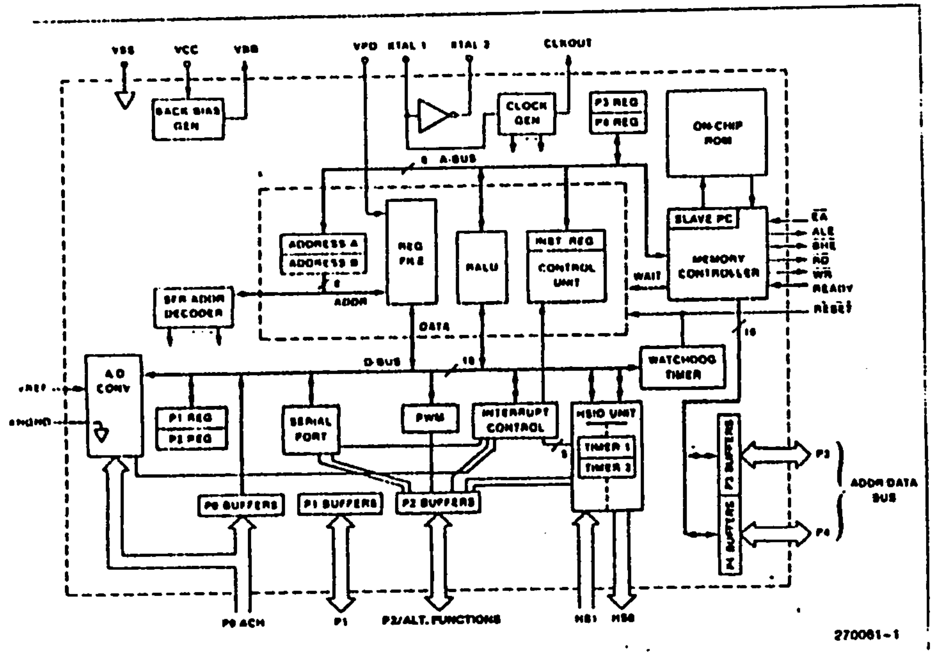
MICROCONTROLLERS AND MICROPROCESSORS

The microprocessor is an integrated circuit that can do arithmetic and logic operations. If the microprocessor is to be used as a controller, one or more memory ICs, one or more input/output (I/O) ports ICs, one or more timers ICs, one or more A/D converters ICs, and one clock circuit are required. These major components are usually connected together in a single printed circuit, making a microcomputer or a microcontroller if the printed circuit is a part of a device [30].

Currently, it is possible to integrate the microprocessor, memory, I/O, A/D, and the clock into a single chip that is called a single-chip microcomputer or microcontroller. Therefore, in this section, two microcomputers or microcontrollers are reviewed. The two microcontrollers are Intel 8096 and Motorola MC68HC16. Both are 16-bit processing power.

1. INTEL 8096

There are two major sections of the 8096; the CPU section and the I/O section. Each of these sections are subdivided into functional blocks as shown in Figure F-1a [31].



a) INTEL 8096 FUNCTIONAL BLOCKS

Major I/O Functions	
High Speed Input Unit	Provides Automatic Recording of Events
High Speed Output Unit	Provides Automatic Triggering of Events and Real-Time Interrupts
Pulse Width Modulation	Output to Drive Motors or Analog Circuits
A to D Converter	Provides Analog Input
Watchdog Timer	Resets 8096 if a Malfunction Occurs
Serial Port	Provides Synchronous or Asynchronous Link
Standard I/O Lines	Provide Interface to the External World when other Special Features are not needed

b) I/O FUNCTIONS

FIGURE F-1

1.1 CPU SECTION

The CPU of the 8096 uses a 16-bit ALU which operates on a 256-byte register file instead of an accumulator. Any of the locations in the register file can be used for sources or destinations for most of the instructions. This is called a register to register architecture. Many of the instructions can also use bytes or words from any where in the 64K byte address space as operands.

1.2 I/O SECTION

Many of the I/O features on the 8096 are designed to operate with little CPU intervention. A list of the major I/O functions is shown in Figure F-1b. The Watchdog timer can be used to reset the system if a software failure occurs. The Pulse-Width-Modulation (PWM) output can be used as a rough Digital to Analog (D/A) converter, a motor driver, or for many other purposes. The A/D converters (ADC) has 8 multiplexed inputs and 10-bits resolution. The serial port has several modes and its own baud rate generator. The High Speed I/O section includes a 16-bit timer, a 16-bit counter, a 4-input programmable edge detector, 4 software timers, and 16-output programmable event generator.

2. MOTOROLA MC68HC16

This MCU can be divided into two sections; the CPU section and the I/O section. Each of these two sections are subdivided into functional blocks [34].

2.1 CPU SECTION

The CPU of the 68HC16 uses a 16-bit ALU. The CPU can address one megabyte of data and one megabyte of program memory. This is done by using 4-bit extension fields from some registers. The CPU can run at a maximum clock speed of 17.78 MHz.

2.2 I/O SECTION

Major peripheral functions are provided on chip. An 8-channel A/D converter is included with 10-bit of resolution. Asynchronous and synchronous serial interface (SCI, SPI) are included. The main 16-bit, free running timer has three input-capture, five output-capture, and a real time interrupt function. A watchdog is also included to protect the system against software failures. Two software-controlled power-saving modes, WAIT and STOP, are available to conserve power.

APPENDIX G

POWER FACTOR ANGLE MEASUREMENT PROGRAM

APPENDIX G

POWER FACTOR ANGLE MEASUREMENT

PROGRAM

Microsoft (R) Macro Assembler Version 4.00 4/10/93 07:02:53

This program is used to measure the power factor angle for energy meetering.

```
0000                        STACK   SEGMENT   PARA STACK 'STACK'
0000  0040[                  DB    64  DUP('STACK')
      53 54 41 43 4B
              ]

0140                        STACK   ENDS

                            * Initialize I/O Ports

0000                        OUR_DATA SEGMENT PARA 'DATA'
= 0301                      B_ADDR           EQU   301H
= 0302                      C_ADDR           EQU   302H
0000      .                 OUR_DATA ENDS

0000                        FUN_C   SEGMENT  PARA 'CODE'

0000                        FUN_P  PROC    FAR
                            ASSUME CS:FUN_C,DS:OUR_DATA,SS:STACK
4000                        ORG   4000H
4000  2B C0                 SUB   AX,AX            ; Set AX=0
4002  FC                    CLD

                            ; Detect Positive going pulse

4003  BA 0301                MOV  DX,B_ADDR        ; Load DX with B_ADDR
4006  EC       MORE1:       IN    AL,DX            ; Load Data from Port-B to
                                                     AL
4007  24 04                 AND   AL,004H          ; Check Port-B, Bit-2 if zero
4009  75 FB                 JNZ   MORE1            ; If not zero goto MORE1
```

```
400B EC      MORE2:    IN    AL,DX            ; Load Data from Port-B to
                                                AL

400C 24 04             AND   AL,004H          ; Check Port-B, Bit-2 if zero
400E 74 FB             JZ    MORE2            ; If zero goto MORE2

                       ; Decrement Counter

4010 BA 0302 MORE3:    MOV   DX,C_ADDR ; Load DX with B_ADDR
4013 B0 04             MOV   AL,04H           ; Load AL=04H
4015 EE                OUT   DX,AL            ; Send a 04H to counter
4016 B0 00             MOV   AL,00H           ; Load AL=00H
4018 EE                OUT   DX,AL            ; Send 0H to counter

                       ; Detect Negative going pulse

4019 BA 0301           MOV   DX,B_ADDR ; Load DX with B_ADDR
401C EC                IN    AL,DX            ; Load Data from Port-B to
                                                AL
401D 24 04             AND   AL,004H          ; Check Port-B, Bit-2 if zero
401F 75 EF             JNZ   MORE3            ; If not zero goto MORE3
                 ;
                       FUN_P  ENDP
4021                    FUN_C  ENDS
                       END   FUN_P


Microsoft (R) Macro Assembler  Version 4.00          4/10/93 07:02:53


Segments and Groups:

          N a m e           Size   Align  Combine Class

FUN_C . . . . . . . . . . . . .   4021   PARA  NONE 'CODE'
OUR_DATA. . . . . . . . . . . .          0000  PARA NONE 'DATA'
STACK . . . . . . . . . . . . .   0140   PARA  STACK      'STACK'

Symbols:

          N a m e           Type   Value  Attr

B_ADDR. . . . . . . . . . . . .   Number       0301

C_ADDR. . . . . . . . . . . . .   Number       0302
```

FUN_P	F PROC	0000	FUN_C	Length = 4021
MORE1	L NEAR	4006	FUN_C	
MORE2	L NEAR	400B	FUN_C	
MORE3	L NEAR	4010	FUN_C	

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APPENDIX H

DUAL TONE MULTIFREQUENCY

(DTMF) RECEIVER

APPENDIX H

DUAL TONE MULTIFREQUENCY

(DTMF) RECEIVER

Figure H-1 shows the DTMF receiver block diagram. In general, the detection scheme is as follows:

The input signal is pre-processed by 60-Hz reject (by implementing the notch filter technique) and then pre-filtered to emphasize the signal and then split into two bands, each of which contains only one DTMF tone group. The output of each band-split filter is amplified and limited by a zero-crossing detector, which converts the sinusoidal signals to square waves. The limited signal in the form of square waves, are passed through tone frequency bandpass filters. After the bandpass filter, the output signal is detected by the amplitude detector and fed to the timing circuit to determine the detection validity within 40 ms. Also, the output is fed to the output decoder, that will represent the decoded tone with an equivalent digit number. the other circuitry gives the control of the output validity. For example, the data strobe from the timing circuit will enable the output from the decoder to be present at the register output. The output register provides the latching.

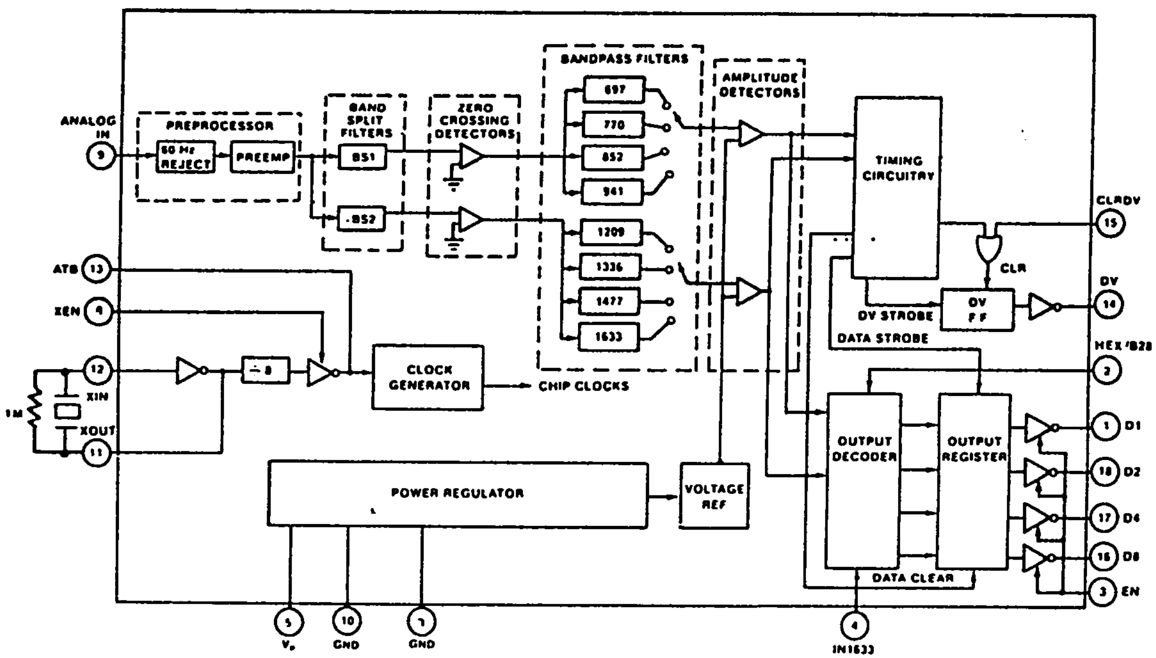

FIGURE H-1, DTMF RECEIVER BLOCK DIAGRAM

The outputs D1, D2, D4 and D8 are CMOS push-pull when enabled (EN-high) and open circuited (high-impedance) when disabled by pulling EN low. These digital outputs provide the code corresponding to the detected digit in the format programmed by the HEX/B28 pin. The digital outputs become valid after a tone pair has been detected and they are then cleared when a valid pause is timed.

The pin HEX/B28 selects the format of the digital output code. When it is tied high, the output is hexadecimal. When tied low, the output is binary coded 2 of 8. The table below describes the two output formats.

	Hexadecimal				Binary Coded 2 of 8			
Digit	D8	D4	D2	D1	D8	D4	D2	D1
1	0	0	0	1	0	0	0	0
2	0	0	1	0	0	0	0	1
3	0	0	1	1	0	0	1	0
4	0	1	0	0	0	0	1	1
5	0	1	0	1	0	1	0	0
6	0	1	1	0	0	1	0	1
7	0	1	1	1	0	1	1	0
8	1	0	0	0	0	1	1	1
9	1	0	0	1	1	0	0	0
0	1	0	1	0	1	0	0	1
*	1	0	1	1	1	0	1	0

#	1	1	0	0	1	0	1	1
A	1	1	0	1	1	1	0	0
B	1	1	1	0	1	1	0	1
C	1	1	1	1	1	1	1	0
D	0	0	0	0	1	1	1	1

A, B, C and D are used for extended keypads.

The Data Valid (DV) pin by going high indicates a valid tone pair is sensed and decoded at the output pins of D1, D2, D4 and D8. DV remains high until a valid pause occurs. Figure H-2 shows the DTMF receiver timing.

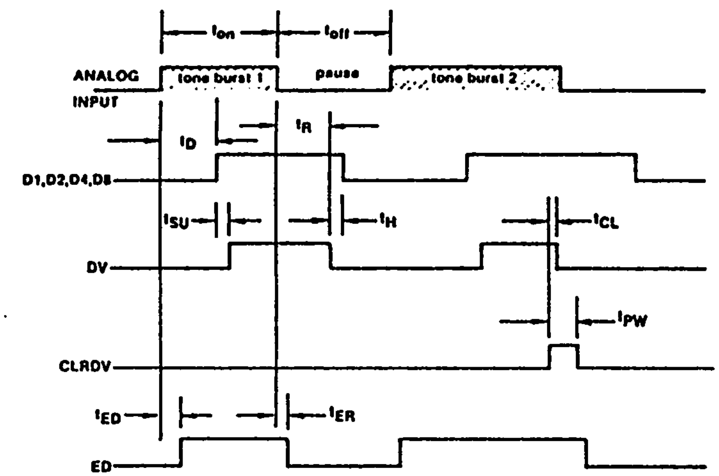

FIGURE H-2, DTMF RECEIVER TIMING DIAGRAM